EXPERT SYSTEM ANALYSIS OF NON-FUEL ASSEMBLY HARDWARE AND SPENT FUEL DISASSEMBLY HARDWARE: ITS GENERATION AND RECOMMENDED DISPOSAL

By

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LIST OF ACRONYMS

AEC	Atomic Energy Commission
AGR	Advanced Gas Reactor
AVM	Advanced Vitrification Method
BPRA	Burnable Poison Rod Assembly
BRC	Below Regulatory Concern
BWR	Boiling Water Reactor
CDB	Characteristics Data Base
CFR	Code of Federal Regulations
DOE	Department of Energy
EFPD	Effective Full Power Day
EFPY	Effective Full Power Year
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
FIS	Federal Interim Storage
FWMS	Federal Waste Management System
GTCC	Greater-Than-Class-C
HANF	Hanford Reservation
HLW	High-Level Waste
HWES	Hardware Waste Expert System
ILW	Intermediate-Level Waste
INEL	Idaho National Engineering Laboratory
LLW	Low-Level Waste
LLWAA	Low-Level Waste Ammendments Act
LLWPA	Low-Level Waste Policy Act
LMFBR	Liquid Metal Fast Breeder Reactor
LWR	Light Water Reactor
MRS	Monitored Retrievable Storage
MTIHM	Metric Tons Initial Heavy Metal
MWD	Megawatt-Days
NARUC	National Association of Regulatory Utility Commissioners
NFA	Non-Fuel Assembly
NRC	Nuclear Regulatory Commission
NWF	Nuclear Waste Fund
NWPA	Nuclear Waste Policy Act
NWPAA	Nuclear Waste Policy Ammendment Act
OCRWM	Office of Civilian Radioactive Waste Management
ONRL	Oak Ridge National Laboratory
PNL	Pacific Northwest Laboratory
PWR	Pressurized Water Reactor
RG&E	Rochester Gas & Electric
SFD	Spent Fuel Disassembly
SNF	Spent Nuclear Fuel
TRU	Transuranic
WVDP	West Valley Demonstration Project
WIPP	Waste Isolation Pilot Project

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Almost all of the effort being expended on radioactive waste disposal in the United States is being focused on the disposal of Spent Nuclear Fuel, with little consideration for other areas that will have to be disposed of in the same facilities. One area of radioactive waste that has not been addressed adequately because it is considered a secondary part of the waste issue is the disposal of the various Non-Fuel Bearing Components of the reactor core. These hardware components fall somewhat arbitrarily into two categories: Non-Fuel Assembly (NFA) hardware and Spent Fuel Disassembly (SFD) hardware.

This work provides a detailed examination of the generation and disposal of NFA hardware and SFD hardware by the nuclear utilities of the United States as it relates to the Civilian Radioactive Waste Management Program. All available sources of data on NFA and SFD hardware are

analyzed with particular emphasis given to the Characteristics Data Base developed by Oak Ridge National Laboratory and the characterization work performed by Pacific Northwest Laboratories and Rochester Gas & Electric. An Expert System developed as a portion of this work is used to assist in the prediction of quantities of NFA hardware and SFD hardware that will be generated by the United States' utilities. Finally, the hardware waste management practices of the United Kingdom, France, Germany, Sweden, and Japan are studied for possible application to the disposal of domestic hardware wastes.

As a result of this work, a general classification scheme for NFA and SFD hardware was developed. Only NFA and SFD hardware constructed of zircaloy and experiencing a burnup of less than 70,000 MWD/MTIHM and PWR control rods constructed of stainless steel are considered Low-Level Waste. All other hardware is classified as Greater-Than-Class-C waste.

Extensive hardware quantity predictions performed by the Expert System are also presented. Good approximations resulted for Combustion Engineering and Babcock & Wilcox reactors, and values for General Electric and Westinghouse reactors were derived from these results. Methods for packaging the hardware for disposal are also presented.

CHAPTER 1
INTRODUCTION

One of the most pressing concerns facing the American nuclear industry is the disposal of the radioactive waste generated by the nation's commercial nuclear power reactors. As of December 31, 1990, 111 commercial nuclear power plants operating nationwide[1] were generating 21% of the nation's commercial electricity.[2] The commercial power industry also generates waste in the course of operations, waste which requires special handling as a result of the radioactivity it contains. Most scientists within the field agree that disposing of this waste in a manner which is safe and effective is technically possible with today's technology.[3] However, ensuring that such disposal will indeed be permanent as well as publicly acceptable has proven to be a formidable task, a task that has come to require the involvement of the federal government as well as the private sector.

The origins of commercial radioactive waste (radwaste) can be found in the year 1957 when the first commercial nuclear power station began operation. Defense-related radwaste made its first appearance even earlier during the Manhattan Project of World War II. In these early days of nuclear energy, formalized methods of waste disposal and waste classification had not been developed, so the methods

used for the management of radwaste were inconsistent. Since that time, several plans for the management and disposal of the various classes of radioactive waste have been developed. However, the implementation of these plans has met with varying degrees of success.

Management concepts for radioactive waste were discussed as early as 1955 in Geneva at the first conference on Peaceful Uses of Atomic Energy. Papers on various aspects of radwaste disposal both on land and at sea were presented by scientists from the United States, the United Kingdom, and Canada.[4] In 1972, Congress made its first attempt at creating a national radwaste program through the Atomic Energy Commission (AEC).[5] Since that time, several changes have been made in the management and regulation of radwaste, including the development of a detailed, if rather complicated, system for classifying radioactive wastes which will be discussed later in this chapter. Progress has been made toward the disposal of radwaste, but the progress is far from uniform and has generally been contested every step of the way. The most progress has been made in the disposal of Low-Level Waste which is generally considered resolved, while the least progress has been made in the disposal of High-Level Waste which is little better off now than it was in 1957. In point of fact, all aspects of nuclear energy and particularly radioactive waste management have become so controversial and contentious as to require acts of Congress to make any progress at all.

Purpose

Almost all of the effort being expended on radioactive waste disposal in the United States is being focused on the disposal of Spent Nuclear Fuel, leaving very little consideration for other areas. One area of radioactive waste that has been considered a secondary part of the waste issue is the disposal of the various Non-Fuel Bearing Components of the reactor core, metal hardware that is activated but not fuel bearing. These hardware components fall somewhat arbitrarily into two categories: Non-Fuel Assembly (NFA) hardware and Spent Fuel Disassembly (SFD) hardware. Neither hardware category is comparable to the weight burden of Spent Nuclear Fuel, but when the waste is measured by volume, these hardware wastes can be essentially equal to Spent Nuclear Fuel. Additionally, there is even more diversity among Non-Fuel Assembly hardware and Spent Fuel Disassembly hardware then there is among fuel assemblies.

These Non-Fuel Bearing Components are somewhat controversial with regard to classification, which can affect jurisdiction. First, while these wastes are certainly either Class C or Greater-than-Class-C (GTCC) Low-Level Waste (LLW), which classification is actually correct is in dispute. As the methods of disposing of these two classes of waste are significantly different, correct classification is important. Furthermore, proper waste classification would clarify the jurisdictional

responsibility as GTCC LLW is the responsibility of the federal government. In such a case, these wastes would fall under the jurisdiction of the Office of Civilian Radioactive Waste Management (OCRWM), so it is important that the waste streams be studied, classified, and quantified. No comprehensive study of these components has yet been published.

The purpose of this work is twofold: 1) to examine in depth the generation and disposal of Non-Fuel Assembly hardware and Spent Fuel Disassembly hardware by the nuclear utilities of the United States as it relates to the Civilian Radioactive Waste Management Program and 2) to build an Expert System which will assist in the prediction of quantities of Non-Fuel Assembly hardware and Spent Fuel Disassembly hardware that will be generated by the United States' utilities and will also estimate the waste classification of these wastes. Several data gathering methods are used to provide the most comprehensive and balanced approach to the problem. The first source is a comprehensive examination of all available literature on the subject. The second is a survey of domestic nuclear utilities for general utility experiences. Direct contact with select utilities for specific information and direct questioning is also utilized, as well as contact with other relevant agencies, corporations, and laboratories. Finally, direct contact with European organizations which have routinely handled similar waste forms is used to provide a

basis for comparison and a view toward actual waste handling experience. The information gathered from these sources is coupled with original analysis to classify and quantify the NFA and SFD hardware waste streams, as well as to make general recommendations on the hardware's packaging and disposal.

Details of the work performed for this dissertation are organized in the following manner. The remainder of Chapter 1 provides detailed background information on radioactive waste classification and an overview of the current status of radwaste disposal programs in the United States. Chapter 2 presents greater detail on NFA hardware and SFD hardware. The sources and general characteristics of these hardware types are discussed, and all domestic data sources on NFA and SFD hardware are analyzed. Hardware classifications are then presented based on original analysis of these and other data. In Chapter 3, the practices and experiences of five foreign nations are examined with emphasis placed on how these experiences can benefit the American waste management programs. Chapter 4 begins with general information on Expert Systems and Expert System shells, and then proceeds to discuss the development of the Hardware Waste Expert System (HWES). The results of the HWES are presented at the end of this chapter. Finally, the conclusions reached as a result of this work are presented in Chapter 5. Areas of research which could benefit from additional study are also identified.

Classes of Radioactive Waste

Radioactive waste classification is primarily based on the concentration of radionuclides in the waste and secondarily on the process which generated the waste. The waste classification system has evolved from its early general categories to the more specific classifications of today. The modern system for the classification of radioactive wastes in the United States involves five major categories of waste. These categories are Low-Level Waste (LLW), High-Level Waste (HLW), Spent Nuclear Fuel (SNF), Transuranic (TRU) waste, and mill tailings.

Mill Tailings

Proceeding in reverse order, mill tailings are the byproducts of uranium mining, extraction, and milling. The average yield of uranium from the uranium ore is about 0.1% to 0.5% and is composed of approximately 0.72% ^{235}U and 99.27% ^{238}U.[6] The natural uranium is then sent through a milling, extraction, and purification procedure to eliminate impurities. Mill tailings are the waste product from this process, which take the form of a slurry of sand and clay particles. The large piles of mill tailings which are currently the subject of the DOE Environmental Restoration Program resulted when these slurries were pumped into impoundment ponds to dry.[7]

The mill tailings retain more than 75% of the radioactivity in the natural ore, but due to the large

quantities of non-radioactive materials in the ore, the volumes of mill tailings are large while the radioactivity concentrations are low.[8] At the end of 1989, the total volume of mill tailings at active mill tailing sites, i.e. those sites not undergoing environmental restoration, was 117.6 X 10^6 cubic meters. Estimates of the total radioactivity in mill tailings are not available.[9]

The mill tailings retain a small percentage of uranium, but the primary isotopes of concern from a radiation protection standpoint are ^{226}Ra and ^{222}Rn.[10] Increased levels of radon are detectable within roughly one kilometer of a mill tailings site. Significant radon release problems have occurred in a few instances where the mill tailings were erroneously used as fill for urban developments.[11] Current management procedures for mill tailings place the dried tailings in piles within enclosures and provide for minimum controls to prevent the waste from entering the water table or from becoming airborne.[12] Unlike other radwastes, mill tailings are disposed of at the site where they are generated.

Transuranics

Transuranic (TRU) waste is material contaminated with more than 100 nCi/g of alpha-emitting radionuclides which have a half-life of at least 20 years and atomic number 92 or greater[13] and includes such isotopes as ^{235}U, ^{238}U, and ^{239}Pu. TRU waste is generally composed of trash such as

rubber gloves, filters, and rags from the reprocessing and refinement of nuclear fuels. This waste is further divided into two sub-classifications based on the degree of contamination. For "Contact-handled" TRU, the shielding provided by the waste package itself is sufficient for safe handling. "Remote-handled" TRU, however, exhibits a dose rate of more than 200 mrem/hr of alpha, beta, and/or gamma emitters, so additional shielding and remote handling are required. Fortunately, remote-handled TRU waste represents only about 2.4% of the total TRU waste inventory as summarized in Table 1.[14]

Since commercial reprocessing is currently at a standstill, virtually all TRU waste is generated during the extraction of plutonium from production fuels for the Department of Defense. The current TRU inventories are located at eight DOE sites: the Savannah River Site; Oak Ridge National Laboratory; Los Alamos National Laboratory; the Rocky Flats Plant; Sandia National Laboratory, Albuquerque; the Nevada Test Site; Idaho National

Table 1. TRU waste inventories at the eight TRU-generating DOE sites as of Dec. 31, 1989.

	Volume	Radioactivity	Heat Load
Buried TRU	190,837.0 cu. m	211,900 Ci	3,300 W
Stored TRU			
Contact	60,057.0 cu. m	1,179,600 Ci	27,200 W
Remote	1,501.9 cu. m	2,486,000 Ci	8,400 W
Subtotal	61,558.9 cu. m	3,665,600 Ci	35,600 W
Total TRU	252,395.9 cu. m	3,877,500 Ci	38,900 W

Engineering Laboratory (INEL); and the Hanford Site (HANF). The vast majority of these wastes are at HANF and INEL. Table 1 shows the total TRU inventory as of December 31, 1989 which is distributed among these sites. The table shows the TRU inventories broken down by classification (remote-handled vs contact-handled) and the waste's current situation (buried vs stored).[15] The inventories listed as "buried" were emplaced prior to 1970, when land burial was considered a safe disposal option for these wastes. In 1970, however, the AEC ruled that additional safeguards should be used to separate TRU wastes from the environment, so all TRU wastes since that time have been placed into retrievable-storage pending a final disposal site. When such a disposal site is available, the previously buried TRU waste will be exhumed, surveyed, and when necessary, moved to the new site.[16]

The Waste Isolation Pilot Project (WIPP) is being constructed at Carlsbad, New Mexico for the disposal of TRU wastes from defense activities. The facility is being constructed at a depth of approximately 2150 feet in a bed of rock salt, one of the earliest media considered for the disposal of radioactive wastes. The WIPP facility has been designed for a nominal operating life of 25 years and has a final design capacity of roughly 178,000 cubic meters of contact-handled TRU and 5100 cubic meters of remote-handled TRU waste.[17] In addition to the disposal of TRU waste, the facility has also been designed "for the purpose of

providing a research and development facility to demonstrate the safe disposal of radioactive wastes resulting from the defense activities and programs of the United States."[18] As such, the first five years of WIPP operation are designated as a test phase during which contact-handled TRU waste and pilot project amounts of HLW from defense activities will be emplaced in the facility for in-situ testing. If the results of the test phase are favorable, additional quantities of TRU, including remote-handled TRU, will be permanently emplaced in WIPP up to the design capacity. The HLW, however, will have to be removed and is eventually destined for the Federal HLW Repository, the same repository that is being pursued for the disposal of commercial spent fuel.

The WIPP facility was originally scheduled to be operational in 1988. The site was essentially completed on schedule, but exhibited some technical uncertainties such as a water seepage condition which caused concern among governmental officials. Accordingly, when Congress failed to approve a land swap between the Department of the Interior and the Department of Energy (DOE), opening of the site was postponed indefinitely to allow time for the land swap to be approved and to give the DOE time to address these concerns.[19] In June of 1990, Secretary of Energy James Watkins announced that the DOE expects to begin the test phase of operations at WIPP as soon as certain, unspecified prerequisites outside of the Department's

control are met.[20] One major prerequisite was met on November 1, 1990 when the Environmental Protection Agency (EPA) approved the DOE TRU waste emplacement test program.[21] The granting of the administrative land withdrawal on January 22, 1991 by the Interior Department's Bureau of Land Management cleared another major obstacle. The DOE now hopes to resolve any remaining issues in time to begin the movement of TRU waste drums from INEL to WIPP in July 1991.[22]

Spent Nuclear Fuel

The third primary category of radwaste is Spent Nuclear Fuel (SNF). The Nuclear Waste Policy Act of 1982 (NWPA) defines Spent Nuclear Fuel as "fuel that has been withdrawn from a nuclear reactor following irradiation, the constituent elements of which have not been separated by reprocessing."[23] In the ideal fuel cycle, SNF is reprocessed and the useful fissile isotopes are extracted for fabrication into new fuel elements. In recent years, however, some countries, including the United States, have opted for direct disposal of SNF, thus eliminating the reprocessing stage. As such, SNF will be treated as HLW until such a time as reprocessing is again initiated for commercial fuels.

In terms of quantities, SNF can be somewhat misleading because of the number of ways in which these quantities can be measured. SNF is the only category of radwaste to

contain large quantities of uranium and plutonium. As a result, quantities of spent fuel are usually measured in terms of metric tons of initial heavy metal (MTIHM). In these terms, the total SNF inventory as of December 31, 1989 was 19,641 MTIHM. However, for purposes of comparison with other waste categories, this measurement is inadequate. Accordingly, the SNF inventory can also be expressed volumetrically as 7920 m^3 or in terms of radioactivity as 2.07×10^{10} Curies.[24] Table 2 shows a comparison of the five major categories of radioactive waste. While SNF represents the smallest volume of radwaste, it also contains the highest level of radioactivity (2.07×10^{10} curies) and the highest volumetric activity (2.61×10^{6} curies/cubic meter).[25] SNF also has a greater waste heat output than any other radwaste category. Hence, SNF is clearly the most concentrated form of radioactive waste.

The high radiation levels exhibited by spent nuclear fuel, coupled with the significant waste heat load it generates, requires special consideration. As a direct

Table 2. A comparison of the volumes and activity levels of the five major radioactive waste classifications as of Dec. 31, 1989.

	Total Volume (cu. m)	Total Curies	Volumetric Activity (Ci/cu. m)	Total Heat Load (Watts)
LLW	3.91E+06	1.91E+07	4.88E+00	4.32E+04
HLW	3.81E+05	1.11E+09	2.91E+03	3.16E+06
SNF	7.92E+03	2.07E+10	2.61E+06	7.83E+07
TRU	2.52E+05	3.67E+06	1.46E+01	3.89E+04
Tailings	1.18E+08	N/A	N/A	N/A

result of these factors, after being discharged from the reactor core, spent fuel is stored in spent fuel pools at the reactor site for a period of time to allow the shorter-lived fission products to decay, thus reducing the heat load and radiation level of the assemblies. In the early days of nuclear power, this cooling period was expected to range from three months to a year, after which the spent fuel would be removed for reprocessing.[26] In practice, however, commercial fuel reprocessing is currently unavailable, so the cooling period has been extended to five years or more. After such a cooling period, the SNF can be relocated to higher density storage racks, or even to dry storage modules. Pressurized Water Reactor (PWR) spent fuel pools are filled with water containing a boron concentration of approximately 2000 parts per million (ppm) whereas Boiling Water Reactor (BWR) spent fuel pools contain only demineralized water without any boron additive. The water serves several safety purposes, the most important of which is the maintenance of subcritical configuration for a k_{eff} of approximately 0.95 or less. Water also provides radiation shielding, and decay heat removal capacity while still allowing visual inspection of the fuel in the fuel pool. The typical spent fuel pool capacity is 4-5 full reactor cores or about 850 fuel assemblies.[27] When the spent fuel pool reaches capacity, as will soon happen at several of the nation's nuclear power plants, several options are available. These options are discussed in detail in Chapter 2.

Since SNF is not currently reprocessed in the United States, the fuel has been accumulating at the nation's reactor sites and a method of disposing of this waste form has been needed. The DOE's current plans as mandated by federal law (see "High-Level Waste," this chapter) call for the development of a Federal HLW Repository as a permanent disposal facility for SNF and HLW. The key point of these plans is to solve the waste management issue now and not to postpone it so as to place the burden on the shoulders of future generations. Furthermore, since the NWPA specifically limits the first repository to a final capacity of 70,000 metric tons of heavy metal,[23] and since SNF is expected to represent the majority of the waste to be emplaced in the repository, its quantities and characteristics are considered extremely important to the Federal Waste Management System and to OCRWM.

High-Level Waste

Also destined for the repository is the next category of radwaste, High-Level Waste. High-Level Waste is a waste product of the reprocessing of spent nuclear fuel. Since reprocessing is designed to extract the plutonium and the remaining usable uranium from spent fuel for fabrication into new fuel elements, HLW contains very little of these elements and instead consists mainly of fission products and other TRU elements.[28] Freshly generated HLW exhibits high levels of radioactivity and generates considerable decay

heat. The projected characteristics of HLW forms (canisters of vitrified HLW) which will be generated at the Savannah River Site, Hanford, Idaho National Engineering Laboratory, and the West Valley Demonstration Project (WVDP) range from a low of 125,200 curies and 382 watts per canister at the WVDP to a high of 416,000 curies and 1158 watts per canister at Hanford.[29] However, since the process which produces these wastes removes a significant portion of the longer lived actinides and dilutes the remaining radioactivity, the volumetric activity of HLW is three orders of magnitude lower than the activity of SNF as shown by Table 2. While the activity and heat load of both SNF and the HLW is expected to drop by a factor of 100 after only 200 years, the HLW will always require less shielding and cooling than the SNF. Some countries like the United Kingdom and France plan to store their HLW for 50 years or more prior to disposal to take advantage of this decay.

The HLW is initially a liquid or sludge and, in the past, has been stored in this form, but over the long term, these storage facilities are prone to developing leaks which necessitate expensive remedial cleanup activities. Accordingly, methods for immobilizing these wastes in solid blocks were found. In the United States, several studies were conducted into various ceramic waste forms, but the most promising waste form was developed in France and is produced by the Advanced Vitrification Method (AVM).[30] In the AVM process, the liquid waste is run through a heated

cylinder which dries the waste. The resulting solid calcinate is mixed with borosilicate glass frit in a ratio of approximately 38% calcinate and 62% glass frit. The mix is then melted and poured into molds, where it solidifies into glass blocks. The AVM process has been in operation at the Marcoule plant in France since 1978 without any unforseen difficulties, and is also being installed in the newer reprocessing facilities at La Hague.[31] The vitrified waste block is the reference waste form for HLW destined for the Federal HLW Repository.[32]

As shown in Table 2, HLW represents the second largest volume of radwaste in the United States, exclusive of uranium mill tailings. A small portion of this inventory is commercial HLW from the commercial fuel reprocessing performed in the 1970's at the West Valley plant in West Valley, New York. During the plant's brief operation, 650 MTU were reprocessed which produced roughly 2000 cubic meters of HLW.[33] The vast majority of HLW in the United States, however, is generated by the production of nuclear materials for national defense activities. The combined volumes of commercial HLW and SNF represented only 2.6% of the total 381,000 m^3 HLW volume extant in 1989 with the remainder being defense HLW. Conversely, the 1.11×10^9 curies in current HLW inventories represent only 5.4% of the total curie content of SNF.[34] Without commercial fuel reprocessing to produce HLW, defense HLW is expected to remain the largest portion of the HLW inventory. However,

the vitrification programs under development at the three DOE facilities and the WVDP should help to reduce the total HLW volume by as much as a factor of ten[35] which will alter the proportions accordingly.

The development of a facility for the ultimate disposal of HLW has always been the responsibility of the federal government. The AEC began investigating the possibility of burying HLW in bedded salt deposits as early as 1957, after such an approach was suggested by the National Academy of Sciences and the National Research Council.[36] The project was abandoned in 1971 by order of Congress and no further significant developments occurred until the passage of the Nuclear Waste Policy Act in 1982. The NWPA instructed the Department of Energy to develop one or more repositories for the final disposal of the nation's SNF and HLW. The three key provisions of the act are the establishment of 1) guidelines and milestones, 2) the Office of Civilian Radioactive Waste Management, and 3) the Nuclear Waste Fund. The guidelines and milestones provided the program with a structure within which to work, thus providing much needed direction to the effort as well as a means of measuring the project's progress. The Office of Civilian Radioactive Waste Management was established as a branch of DOE whose only responsibility was the development and operation of a federal repository. Finally, the monies paid into the Nuclear Waste Fund by the utilities provided a means of paying for the repository, and all the associated work which

did not require federal expenditures and simultaneously committed the utilities to using the facility once established. The Nuclear Waste Fund is discussed in greater detail later in this section.

OCRWM was duly established and began work on the repository. In December 1984, as per the NWPA, the DOE nominated nine candidate sites for consideration. After completing the Environmental Assessments for these sites in April 1986, three of the sites were recommended to the President for site characterization. These sites were located in Deaf Smith County, Texas; Yucca Mountain, Nevada; and the Hanford Reservation, Washington. The next stage laid out by the NWPA involved site characterization of all three sites, and a continued search for sites east of the Mississippi River as candidates for a second repository. However, all "efforts to survey potential sites in the eastern part of the United States were hotly contested . . . [so] citing lack of need, the DOE suspended its site-selection program for the second repository."[37]

By 1987, site characterization was proceeding at only one site (Yucca Mountain), and the entire program was faced by so much opposition that Congress was required to intervene with the Nuclear Waste Policy Amendment Act of 1987 (NWPAA). Based on the concept that "the U.S. problems are political and not technical, i.e. that the storage of HLW is no big technical problem,"[37] the NWPAA sought to streamline the selection process. The most important

features of the NWPAA are that 1) the site characterization was officially narrowed to only the Yucca Mountain site, 2) the second repository is canceled until a report on the need for such a facility is submitted between the years 2001 and 2010, and 3) financial incentives are now included in the site selection process to encourage state cooperation.[37] Once the site characterization has been completed, then OCRWM must justify the site, and the site must be reviewed and approved by the Nuclear Regulatory Commission (NRC). The review procedure is expected to be long and time-consuming, thus contributing significantly to the delay time until the repository can begin operation.[38] This delay, however, may actually prove to be relatively short in comparison to the other delays the program has already suffered.

The NWPA set a target date of January 31, 1998 for the first repository to begin receiving spent fuel from the utilities. By 1987, the project had fallen sufficiently behind that DOE proposed postponing the initial operational date of the repository to the year 2003.[39] This target date was subsequently confirmed by the enactment of the NWPAA. Unfortunately, due mainly to the obstacles presented by the state of Nevada, the project is once again stalled and the year 2010 is currently considered the earliest date for first operation.[40] To date, Nevada has refused to issue the necessary environmental permits needed by the DOE to perform site characterization studies of Yucca Mountain.

On January 25, 1990, DOE filed suit with the U.S. District Court alleging that Nevada "has prevented the federal agency from carrying out necessary site investigation work by unlawfully refusing to act."[41] This suit was subsequently decided in favor of the DOE, and Nevada's appeal was turned down by both the U.S. Court of Appeals in September 1990 and by the U.S. Supreme Court on March 4, 1991. Before beginning work, however, DOE must now await the outcome of another lawsuit which is designed to force the issuance of the needed permits. As this case and its subsequent appeals are not likely to be resolved until late in 1992, DOE has also asked Congress for the authority to conduct the site investigation without regard for the opposition presented by Nevada.[42] If granted, then the DOE can proceed with the characterization work without further delay. In any case, no definitive schedule for the repository's development will be possible until the legal battle is resolved, and even then, other delays are extremely likely.

A further consideration when discussing the Federal Waste Management System (FWMS) is the Nuclear Waste Fund (NWF), which was created by the NWPA and is "funded with an assessment of one mill per kilowatt-hour on all electricity generated at commercial nuclear plants."[37] Approximately $4 billion has been paid into the NWF by the utilities from the program's inception through the end of fiscal year 1989. The NWF's balance at the end of the fiscal year was $2.2 billion.[43] The approximate unaudited balance at the end of

the 1990 fiscal year was $2.6 billion.[44] Since the NWF's inception, the General Accounting Office (GAO) and the DOE have been in dispute as to whether or not these assessments will be sufficient, with the GAO urging for an increase in the assessment.[45] However, as of November 1990, the DOE did not feel it necessary to increase the waste fee.[46] In any case, the utilities are already concerned about getting their money's worth from the waste fund. The same contract which requires the utilities to pay the one mill per kilowatt-hour fee also stipulated that the DOE must begin accepting SNF no later than January 31, 1998.[47] Due to innumerable programmatic delays and continuous opposition to its efforts, the DOE will be unable to fulfill its end of the bargain unless legislative changes are made. The only likely method foreseen at this time by which the DOE can meet the 1998 deadline is the development of a Monitored Retrievable Storage (MRS) facility which is not coupled to the development of the repository. As things stand now, the utilities must continue to hold the SNF after having collectively paid out some $4 billion without any demonstrable gain.

The utilities have also shown concern over the manner in which the waste fee is calculated. Since the inception of the NWF, the utilities have won two judgements concerning the calculation of the waste fee.[48] In December 1985, the court ruled that the waste fees should be based on net electricity production as opposed to gross electricity

production, taking into account power used on the plant site.[49] In March 1989, the court further ruled that transmission losses should also be excluded from the calculation.[50] The fees are now based solely upon the net electricity sold to consumers. Before the NWPAA was enacted, "the electric utility industry was prepared to stop its contributions to the Nuclear Waste Fund . . . if a moratorium [on HLW disposal] had been legislated."[37] Now with the HLW program once again stalled in legal deliberations, Congress may be required to act once again to expedite the development of the HLW repository.

Low-Level Waste

The final major category of radwaste is also the broadest in definition. Low-Level Waste is a catchall category for otherwise uncategorized radioactive wastes, or more specifically, "Low-level waste . . . [is] radioactive waste not classified as high-level radioactive waste, transuranic waste, spent nuclear fuel, or byproduct material."[51] Within the LLW classification, there are four further subdivisions -- Class A, Class B, Class C, and Greater-Than-Class-C -- which require progressively more stringent precautions for disposal. Class A, B, and C wastes are currently disposed of by shallow land burial. Class A waste is regarded as the least hazardous and thus requires the least precautions while Class C wastes are subject to more restrictive guidelines for disposal.

Greater-Than-Class-C waste, on the other hand, is generally regarded as not suitable for shallow land burial and thus cannot be treated like other Low-Level Wastes.

LLW classifications are determined by measuring the concentrations of certain radionuclides within the waste package which are specified in 10CFR61 as follows:

> First, consideration must be given to the concentration of long-lived radionuclides (and their shorter-lived precursors) whose potential hazard will persist long after such precautions as institutional controls, improved waste form, and deeper disposal have ceased to be effective. . . . Second, consideration must be given to the concentration of shorter-lived radionuclides for which requirements on institutional controls, waste form, and disposal methods are effective.[51]

The actual isotopes of concern are listed in two groups in 10CFR61 and are reproduced here in Table 3. The isotopes in Group 1 are the long-lived radionuclides referred to above while the Group 2 isotopes are the shorter-lived radionuclides. Each of these nuclides is listed within one of two tables given in 10CFR61 along with its allowable concentration limits.[52] By determining the ratio of the concentration of each nuclide in the waste form to the value

Table 3. Critical isotopes listed in 10 CFR 61 for LLW classification with their half-lives.

Group 1 (long lived)	Group 2 (short lived)
C-14 (5730 y)	H-3 (12.26 y)
Ni-59 (80,000 y)	Co-60 (5.24 y)
Nb-94 (20,000 y)	Ni-63 (92 y)
Tc-99 (210,000 y)	Sr-90 (28.8 y)
I-129 (1,600,000 y)	Cs-137 (30 y)
	Pu-241 (13 y)
	Cm-242 (163 d)

given for that nuclide in the tables, the LLW classification of the waste can be determined. If the ratio is greater than one, the waste is classified as GTCC LLW. Additionally, even if the individual nuclide concentrations do not exceed the limits, the waste may still be GTCC if the combination of the ratios of the nuclides is too great. In this case, the individual ratios calculated earlier for the individual isotope concentrations are summed together, and if the resulting sum is greater than one, then the combination of nuclides is considered to be too great for disposal as LLW, so the waste is classified as GTCC. In both cases, the waste is then required to meet all the handling and disposal criteria for GTCC wastes. Otherwise, depending on the actual concentrations, the waste will be either Class A, B, or C and may be disposed of by shallow land burial. In the specific case of Non-Fuel Assembly and Spent Fuel Disassembly hardware, since these materials are activated metals, only four of the isotopes listed in Table 3 are measured (^{14}C, ^{59}Ni, ^{63}Ni, and ^{94}Nb), but the procedure is otherwise as described above.

The disposal of LLW is the most advanced radwaste program in the United States as such disposal has been routinely conducted since 1962 when the first commercial LLW disposal site opened at Beatty, Nevada. The number of sites increased to six in 1971 before a reduction to three in 1979. These three remaining sites are located in Barnwell, South Carolina; Richland, Washington; and Beatty, Nevada.

In 1979 and 1980, the states which hosted these sites became concerned about the inequity of the LLW disposal situation and made efforts to close their sites to LLW from other states. These actions in turn prompted Congress to pass the Low-Level Waste Policy Act (LLWPA) of 1980 and later, the Low Level Waste Amendments Act (LLWAA) of 1985.[53] Under the provisions of these Acts, each state is responsible for the permanent disposal of its own LLW. The Acts encouraged the states to form "compacts" in order to jointly develop a common site for use of all the member states. Several milestones were provided within the Acts to ensure that the states did in fact develop such sites. Failure to meet these deadlines is penalized by escalating surcharges on disposal at existing LLW sites with this cost being born by the waste generators. The final deadline was originally set for December 31, 1986 by the LLWPA, but was subsequently postponed to December 31, 1992 by the LLWAA when it became apparent that the procedure for forming and approving regional compacts was proceeding much slower than anticipated. After this final deadline, the LLW from generators in any state that does not have an operational LLW disposal site, or that does not belong to a compact that does, may be excluded from all other disposal sites. However, in such a case, the generators are entitled to demand that the state take title to the LLW which they are thus unable to dispose of.[54,55] How this action will be accomplished if the option is exercised is still an

unresolved issue. As 1992 approaches, most compacts are still developing their sites and do not expect the sites to be operational before 1995. So, whereas progress is being made toward the eventual establishment of compact LLW sites, it is unlikely that the sites will be operational early enough to meet the deadline set by the LLWAA. The compacts are currently examining options for interim measures until their sites are operational.

Whereas the techniques for the disposal of LLW is clearly established, the disposal of GTCC LLW is not so clearly defined. Of the twelve isotopes listed in Table 3, ten are used to judge between Class C and GTCC wastes. The isotopes ^{3}H and ^{60}Co have no Class C limit and therefore can be present in any concentration without making the waste GTCC. Furthermore, when the waste being classified consists of activated metals, only four isotopes are of importance. These isotopes are Carbon-14 (^{14}C), Nickel-59 (^{59}Ni), Nickel-63 (^{63}Ni), and Niobium-94 (^{94}Nb). As has been previously mentioned, when the isotope concentrations exceed the allowable limits, the waste is not considered suitable for shallow land burial, but exactly what manner of disposal is acceptable was not specified in 10CFR61.

The LLWAA "charged the DOE with the safe disposal . . . of GTCC waste from any generator,"[56] but the DOE was not prepared to make any plans for its disposal at that time. The DOE position maintained that it would require several years to set up a GTCC program and then an additional 8 to

10 years before a permanent disposal site could be constructed. The NRC, on the other hand, has taken steps toward the immediate resolution of the GTCC problem. The NRC, to whom OCRWM is answerable under the provisions of the NWPA, has issued a final ruling which stipulates that "radwaste that exceeds the upper bounds for Class C low-level waste must be disposed of in a geological repository suitable for high-level waste disposal,"[57,58] unless another suitable facility is designed by the DOE and approved by the NRC. Since considerable quantities of GTCC waste are expected from reactor decommissioning activities, the development of a separate facility is a serious possibility, but no firm plans to develop such a facility have been announced.

A significant portion of potential GTCC wastes fall into two categories, Non-Fuel Assembly hardware and Spent Fuel Disassembly hardware, two waste streams which will be further discussed in Chapter 2. Both the NFA hardware and SFD hardware waste streams are directly related to the spent fuel waste stream, both are subjected to a similar irradiation history, and both are constructed of similar materials. The activated metals which comprise these waste streams will be classified as either Class C or GTCC LLW. The approximate radioisotopic contents of many of these components have been calculated by the ORIGEN2 code and included in the Characteristics Data Base[59] (CDB), so an estimate of the classification of these waste components can

be made using the CDB. A preliminary analysis of this data performed by the author in preparation for this work indicated that most, if not all, of these hardware elements will be GTCC waste.

In most of the hardware elements delineated in the CDB, the single worst element, i.e. the element which has most often exceeded its Class C limit, is ^{94}Nb. Niobium has a half life of 20,000 years, so materials containing ^{94}Nb remain radioactive for a long period of time. The decay of niobium has a high decay energy (2.1 MeV), 75% of which is emitted as gamma radiation. Niobium also has a high degree of solubility in water which causes niobium to pose a potential leaching problem. For these reasons, niobium has been given a very low Class C limit of only 0.2 curies per cubic meter. In certain materials like both Zircaloy-2 and 4, niobium is only present at impurity levels, but for the irradiation levels to which the hardware components are exposed, "trace quantities may be sufficient for the irradiated material to exceed Class C limits."[59] In some other materials, there is an even greater concentration of niobium, because

> there has also been a rapid increase in recent years in the use of niobium in the steel industry. Small amounts of niobium markedly increase the yield strength of mild steel plates and prevent weld decay and intergranular corrosion in stainless steels; . . . In a similar way, the addition of niobium can increase the high-temperature strength of high-strength heat-resisting steels and superalloys such as are used in gas turbines and similar environments.[60]

Thus, the quantities of niobium used in the various reactor metals is very important to the eventual determination of the activated metals' waste classification.

Of the other three critical isotopes, only ^{59}Ni possesses a half life of a magnitude similar to that of ^{94}Nb, namely 80,000 years. However, the decay of ^{59}Ni is less energetic (1.07 MeV) and releases no gamma radiation, so it was given a higher Class C limit of 220 curies per cubic meter. On the other hand, ^{63}Ni is a comparatively short-lived nuclide with a half life of 92 years. Because it is expected to decay away in a relatively short time span, it has a correspondingly high Class C limit of 7000 curies per cubic meter, the highest allowed concentration of any critical isotope in an activated metal. Finally, ^{14}C falls in between these two extremes with a half life of 5730 years, and a Class C limit of 80 curies per cubic meter. All three of these nuclides are found in most reactor materials such as inconel and stainless steel. All three also often exceed their respective Class C limits, but, in most cases, not before niobium has already done so.

The foregoing discussion serves to illustrate the complexity of the radioactive waste management issue. Whereas some aspects of radwaste disposal are technically challenging, the most difficult problems for radwaste programs to overcome are political in nature. Some of the most important milestones for radwaste disposal are summarized in Table 4, the clear majority of which are

Table 4. A chronology of some of the important dates concerning radioactive waste disposal.

1955	First conference on the Peaceful Uses of Atomic Energy.
1957	First commercial nuclear power reactor.
1962	First commercial LLW site at Beatty, NV.
1972	First attempt by Congress to establish a national radioactive waste program.
1979	Washington and Nevada temporarily close LLW sites; South Carolina reduces allowable disposal at Barnwell.
1980	Low-Level Waste Policy Act (LLWPA) enacted.
1983	Nuclear Waste Policy Act (NWPA) enacted.
1985	Low-Level Waste Policy Amendments Act (LLWAA) enacted.
1987	Nuclear Waste Policy Amendments Act (NWPAA) enacted.
1991	Potential start-up of test phase at WIPP.
1993	Deadline for the development of Compact LLW sites as set by the LLWAA.
1995	Expected start-up date for most Compact LLW sites.
1998	Contractual deadline for the Department of Energy to begin accepting SNF from the utilities as set by the NWPA.
2003	First operational date of the Federal HLW Repository as set by the NWPAA.

political events or the outcome of political events. If programs like WIPP and the Compact LLW disposal sites are successful, then progress in the disposal of HLW and SNF may become politically possible.

Before proceeding, mention should be made of two further waste categories. The first is mixed wastes, or wastes which are considered to represent both a radioactive and nonradioactive toxicity hazard. Due to the nature of these wastes, they fall under the jurisdiction of both the NRC and the EPA. The resulting regulatory situation is complicated, often contradictory, and beyond the scope of this work. The second category is Below Regulatory Concern (BRC) radioactive waste. This is waste which contains radioactivity at such low levels as not to be considered a significant hazard. The NRC has recently drawn considerable criticism for issuing a BRC policy which would classify some Low-Level Wastes as BRC wastes.[61] Discussion of this waste category is also beyond the scope of this work.

Notes

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[10]Integrated Data Base, 3.

[11]Tang, 278.

[12]Tang, 2-12.

[13]Integrated Data Base, 2.

[14]Integrated Data Base, 75.

[15]Integrated Data Base, 81.

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[17]Tang, 187-92.

[18]96th U.S. Congress, Department of Energy National Security and Military Application of Nuclear Energy Authorization Act of 1980, Public Law 96-164, 1980.

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[20]"DOE Endorses WIPP Tests," Nuclear News 33, no. 10 (August 1990): 95.

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[22]"Land Withdrawal Okayed, Giving DOE Access to WIPP," Nuclear News 34, no. 3 (March 1991): 78-80.

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[27]Tang, 54.

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[32]Tang, 106-22.

[33]Tang, 103.

[34]Integrated Data Base, 5, 47.

[35]Integrated Data Base, 47-9.

[36]Tang, 93.

[37]John Graham, "Amending NWPA to Prevent a Moratorium," Nuclear News 31, no. 3 (March 1988): 42-7.

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[45]"GAO Cites Cost Hikes, Delays in DOE Program," Nuclear News 30, no. 14 (November 1987): 94-5.

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[49]"Utilities Win Waste Fee Suit," Nuclear News 29, no. 1 (January 1986): 95.

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CHAPTER 2
DOMESTIC HARDWARE WASTE HANDLING

Due to the unavailability of commercial fuel reprocessing and the lack of an acceptable facility for SNF disposal, i.e. the federal repository, SNF is continuing to accumulate at the nation's nuclear reactor sites. As a result, many utilities are currently faced with the problem of storing far greater quantities of spent fuel than their spent fuel pools are capable of accommodating.[1] When most of these plants began construction,

> spent-fuel storage was not considered to be a problem . . . [as] it was assumed that all spent fuel would be reprocessed. Government decisions in the 1970's and the economics of the 1980's, however, served to eliminate the reprocessing option in the United States, thus putting the burden of spent fuel storage onto utilities that were not prepared for it. The spent-fuel pools of many older units simply could not accommodate all spent fuel [generated] over the life of the plant.[2]

A 1988 study published by NARUC (the National Association of Regulatory Utility Commissioners) found that 55 reactor sites were expected to reach their authorized capacity by 1998. The report further stated that if all 55 of these reactors made full use of reracking and rod consolidation, 29 units would still exhaust their pool capacity by 1998.[1] Congress acknowledged this difficulty in the NWPA by including provisions whereby

> the DOE may provide Federal Interim Storage (FIS) for spent fuel up to a total of 1900 metric tons of heavy metal [about 19 cores] for nuclear power plants that have done everything possible to provide storage for their spent fuel and through no fault of their own cannot do so and would have to shut down if additional storage were not provided.[3]

Nevertheless, the initial efforts were required of the utilities who were thus forced to find methods of increasing the available spent fuel storage space. The option for FIS expired in January 1990 without being utilized. The amount of space required at any given plant will depend on the age of the plant and on when the repository (or an MRS facility) is actually able to receive spent fuel.

Nuclear reactors maintain a "full-core reserve" in their spent fuel pools. This is not considered a safety matter, but instead allows added operational flexibility, such as being able to unload the entire core during pressure vessel inspections.[4] The obvious drawback to maintaining a full core reserve is the reduction of available storage space in the spent fuel pool. To relieve this storage space problem, the utilities have examined several alternatives for both long-term and short-term solutions. The short-term solutions are spent fuel pool reracking, intra-utility transshipment, and fuel rod consolidation, while long-term solutions include the construction of additional spent fuel storage pools, and modular dry storage. Reracking has been and will continue to be used extensively to provide extra time to explore other, long-term alternatives. Transshipment is also commonly used where possible, but is only

available to utilities which have multiple reactors or an alternate storage pool.

Reracking involves the replacement of the existing spent fuel storage racks with new racks to decrease dead space and increase storage capacity. The original spent fuel rack designs were conservatively designed with regard to criticality concerns at the direction of the NRC, but 30 years of commercial reactor experience, the use of poisons within the rack structure, and improved calculational techniques have allowed for new racks to be installed while still meeting all safety and seismic requirements. By taking into account the burnup of the fuel and by inserting borated steel plates between storage cells whenever necessary, the number of fuel assemblies that can be stored in the pool can be increased by a factor of four or five.[4] For example, reracking performed by the Commonwealth Edison Company resulted in an increase in "spent-fuel storage at LaSalle-2 from 1080 to 4078 assemblies."[5] Reracking requires NRC review and approval, but the only real limiting concern is the ability of the fuel pool to handle the additional floor loading.

The second short-term solution, transshipment, is the cheapest option for increasing a reactor's spent fuel storage space and, when available, is usually the first option to be exploited. Transshipment is the transfer of spent fuel from one reactor's spent fuel pool to another reactor's spent fuel pool. When a utility has new reactors

coming on-line and older reactors already on-line, the space in the new reactor's pool can be used by both reactors to buy time. Additionally, in some cases where a new reactor is being built by a utility which has other nuclear units, the spent fuel pool of the new reactor is being intentionally oversized to allow room for fuel from the older reactor to be stored there. When used together, transshipment and fuel pool reracking can supply the needed storage space for several year's worth of spent fuel. However, the storage space available through these methods is strictly limited and is, in most cases, insufficient to accommodate all the spent fuel generated before the Federal Repository goes on-line.

After transshipment and reracking possibilities have been exhausted, three other options still remain. One such option is to build an additional spent fuel storage pool or to expand an existing one, but this option is more expensive than both modular dry storage and rod consolidation. Also, due to a spent fuel pool's reliance on active cooling systems, the spent fuel pool requires additional maintenance and safety systems. Due to these considerations, no new pools have been built to date.

Thus, a second, more flexible option is modular dry cask storage. When used,

> dry storage employs passive cooling of spent nuclear fuel in large metal casks, vaults, drywells, or concrete silos. Following storage in pools for several years, several intact or consolidated spent nuclear fuel assemblies can be loaded into the dry storage modules for extended

storage above ground at nuclear power plant sites.[6]

This method has the advantage of being modular; additional storage space can be added one unit (be it cask, silo, or whatever) at a time as additional storage capacity is required. However, each additional unit is an additional capital outlay and, for some reactors, a large number of such casks will be required. Dry storage removes "cooled" fuel from the spent fuel pool providing space for hotter, fresh fuel assemblies. The storage modules, whether casks, vaults, or silos, will need to be stored within the exclusion area around the reactor. Only the three San Onofre reactors are expected to have trouble accommodating dry storage modules. These reactors are situated on federal land, the lease for which prohibits the storage of SNF at any location other than within the spent fuel pool. However, in order to prevent the premature shutdown of these plants, the government may lift this restriction to permit dry storage before the storage capacity of the fuel pools is exhausted in 1996.[2]

The passive cooling requirement for dry storage means that no active or moving components, such as pumps or fans, are required to cool the assemblies within these modules. The possibility of the storage casks also doubling as shipping containers is also being considered. If possible, the casks would then serve double duty, and would reduce the amount of fuel handling that will be required. Several demonstration projects for dry cask storage were performed

in the mid-1980s in cooperation with the DOE and the Electric Power Research Institute (EPRI).[7] In July 1986, Virginia Power became the first utility to be licensed for dry cask storage.[8] Castor V metal storage casks which are manufactured by General Nuclear Systems, Inc. and hold 21 intact PWR fuel assemblies are in use at the Surry Nuclear Power Stations,[9] as are Nuclear Assurance Corporation NAC-I28 S/T casks and Westinghouse MC-10 casks. Including the two Surry reactors, fifteen reactors operated by eight utilities had already opted for modular dry storage by January 1991.[10] In July 1990, the NRC issued new regulations which permit dry storage to be conducted in certain approved casks under the general plant license. This eliminates the need for a special license and licensing procedure for such storage in the approved casks,[11] which should make dry storage an even more attractive interim storage option for many utilities.

The third and final option which has been investigated is spent fuel rod consolidation which, like transshipment and reracking, relies on making more efficient use of existing storage capacity. This option has the advantage that

> rod consolidation technology is an extension of previous experience with the reconstitution of [failed] fuel assemblies in storage pools, and is an alternative for [increased storage in] pools that have sufficient structural strength to safely support the added weight.[6]

Hence, rod consolidation is not so much a new idea as it is an extension of an old idea. In execution,

> rod consolidation is a process that involves dismantling the fuel assembly and rearranging the spent-fuel rods into a close-packed geometry in a storage canister. As a storage technology, rod consolidation has the potential to double the existing water basin storage capacity.[6]

Cooperative studies in rod consolidation have also been conducted and "target consolidation ratios of 2:1 or better have been demonstrated,"[12] excluding SFD hardware.

The process of rod consolidation involves dismantling the fuel rod assemblies and placing the fuel rods into canisters designed for this purpose. The consolidation equipment is designed to extract the fuel rods from the assembly and then place the rods into a consolidation canister, changing them to a triangular pitch in the process. The triangular pitch allows more efficient packing of the fuel rods, which is necessary to achieve the 2:1 consolidation ratio. The majority of the designs extract one fuel rod and handle one assembly at a time, but there are a few designs which operate differently. U.S. Tool and Die, Inc. has a design, in which "rods are pulled by rows from the fuel assembly and guided down directly into the canister through a stationary funnel."[13] The rods are placed in the triangular array inside the canister. Westinghouse has a design which transfers all the fuel rods from an assembly simultaneously. The rods are moved to a transition canister, mechanically rearranged into a triangular array, and then placed in the storage canister.[14] The Fuel Master system, designed jointly by Babcock & Wilcox and Numatec, pulls only one rod from an

assembly at a time, but works on two assemblies simultaneously.[15] The major differences between these systems are the speed with which they work and the amount of automation used in the process.

As a storage technology, rod consolidation has both advantages and disadvantages, just like dry cask storage. On the positive side, consolidation is an extension of existing technology/methodology, and should therefore be easier to implement than dry storage. Consolidation has the potential to double the storage capacity of the reactor's existing spent fuel pool, thus minimizing the capital outlay required of the utility. There is only the one time cost of consolidation equipment, which should theoretically cost less than a number of casks of equal capacity. As mentioned earlier, consolidation also doubles the fuel pool floor loading which could be a limiting condition for some reactors. However, rod consolidation techniques can also be used in combination with the dry cask storage techniques (if the particular cask is designed to accommodate consolidated fuel, specifically the additional heat load and increased radiation dose rate associated with the consolidated fuel) in which case only half the number of casks will be required for any particular storage requirement. In early 1988, in a test at INEL jointly sponsored by DOE and EPRI, a Transnuclear TN-24P metal storage cask was loaded with 24 consolidated fuel canisters. The cask performed well in terms of both heat transfer and radiation shielding. Of

particular note was that the gamma dose rate for the consolidated fuel was significantly lower than the gamma rate for intact fuel because the primary gamma sources, i.e. the SFD hardware elements, had been removed.[16] A 1988 survey of dry storage cask designs further indicated that the majority of cask designs could accommodate consolidated fuel canisters.[17] If a similar performance can be achieved when rod consolidation is used with shipping casks, only half the number of shipping casks and half the number of shipments would be required. This, of course, excludes the SFD hardware generated by consolidation which may be shipped to a separate facility for disposal. Rod consolidation thus has the potential for use within the FWMS, regardless of its use or lack of use by the utilities. Consolidation performed at an MRS facility would result in a reduction in the number of spent fuel shipments required, while consolidation performed at the repository would reduce the number of waste packages required.

On the negative side, some reactors may not be able to use rod consolidation, because the structural base of the spent fuel pool is not designed to carry the added weight of the consolidated spent fuel. However, they might be able to use consolidation in conjunction with appropriately designed dry storage casks, as previously mentioned. Rod consolidation has also been shown to have adverse effects on reactor operations in two primary ways. First, assemblies tend to develop a film of "crud" while in the reactor core

which, when the fuel rods are pulled from the assembly, is broken loose. This debris reduces the visibility in the spent fuel pool and could result in higher exposure rates to the operators.[18] Secondly, consolidation activities are extremely time-consuming and the man-hours required to perform consolidation operations would place a severe financial burden on the plant, as well as interfere with other required work around the reactor site.[19] Consolidation also increases the risk of damaging or breaking fuel pins when they are withdrawn from the assembly. These damaged pins would then require special treatment and pose an additional storage problem. Only a few of the thousands of fuel pins consolidated during the course of the various demonstration programs were damaged, in spite of several of the programs purposely consolidating warped or deformed rods. This demonstrates that rod breakage is not a major factor; nevertheless, the concern cannot be entirely dismissed.

A further difficulty revealed by the demonstration programs is that the rod consolidation process is not as efficient as was originally anticipated. Whereas the desired 2:1 consolidation ratio has been successfully achieved for the spent fuel rods, the consolidation process creates another waste, the fuel skeleton, the disposal of which has not been adequately demonstrated. If the design compaction goal for these skeletons (10:1) could be achieved, consolidation would result in a 40% increase in

storage space as shown in Table 5. However, the consolidation demonstration programs have had a difficult time reliably achieving this ratio. Accordingly, current consolidation technology produces less than a 40% increase in available space and, at this point, becomes economically questionable. Two alternative methods for handling this hardware are being studied. One option is to store the compacted hardware in canisters above the spent fuel rack. The most important consideration for this method is maintaining an optimum depth within the pool to limit personnel exposure. The second option is immediate disposal of the SFD hardware at LLW sites. However, this option is contingent upon the waste classifying as LLW, an issue which is currently being studied and whose evaluation is one major purpose of this work. Finally, the continuing delays in the repository scheduling have further hurt rod consolidation in that consolidation alone is no longer sufficient to provide adequate additional storage space at most reactor sites. Accordingly, most utilities have decided to pursue dry cask storage initially and to reconsider the use of consolida-

Table 5. Typical generation of storage space by rod consolidation (in terms of fuel assembly spaces).

Assemblies to be Consolidated:	10
Consolidated Canisters (2:1) :	5
Compacted Skeletons (10:1) :	1
Empty Spaces Created :	4

Increase in Storage Space:
(4/10) X 100% = 40%

tion, possibly in conjunction with dry cask storage, sometime in the future.[18,19]

As of April 1991, no utility has announced its intention to pursue a full-scale rod consolidation campaign. Those utilities which had announced such plans have since canceled them for the foreseeable future. The most notable example of this is Northern States Power which had intended to conduct a 1000 assembly campaign at their Prairie Island Nuclear Generating Plant,[18] but have since switched to using dry storage in Transnuclear TN-40 metal casks.[10] Nevertheless, as rod consolidation may be used in the future by either utilities or the FWMS, an analysis of the resulting waste stream, SFD hardware, is in order.

When all of the fuel rods have been removed from the fuel assembly, the empty assembly skeleton remains behind. The components which comprise the skeleton include, but are not limited to, guide tubes, grid spacers, and top and bottom nozzles and are known collectively as Spent Fuel Disassembly hardware. Figure 1 shows the upper end fitting for a Combustion Engineering PWR fuel assembly. The diagram provides a detailed illustration of just a few of the SFD hardware components associated with a fuel assembly. Additional spacer grids, typically a total of eight to ten, are spaced evenly over the length of the assembly. The bottom of the assembly also has a lower end fitting similar in size and material to the upper end fitting. These components were previously expected to be disposed of as

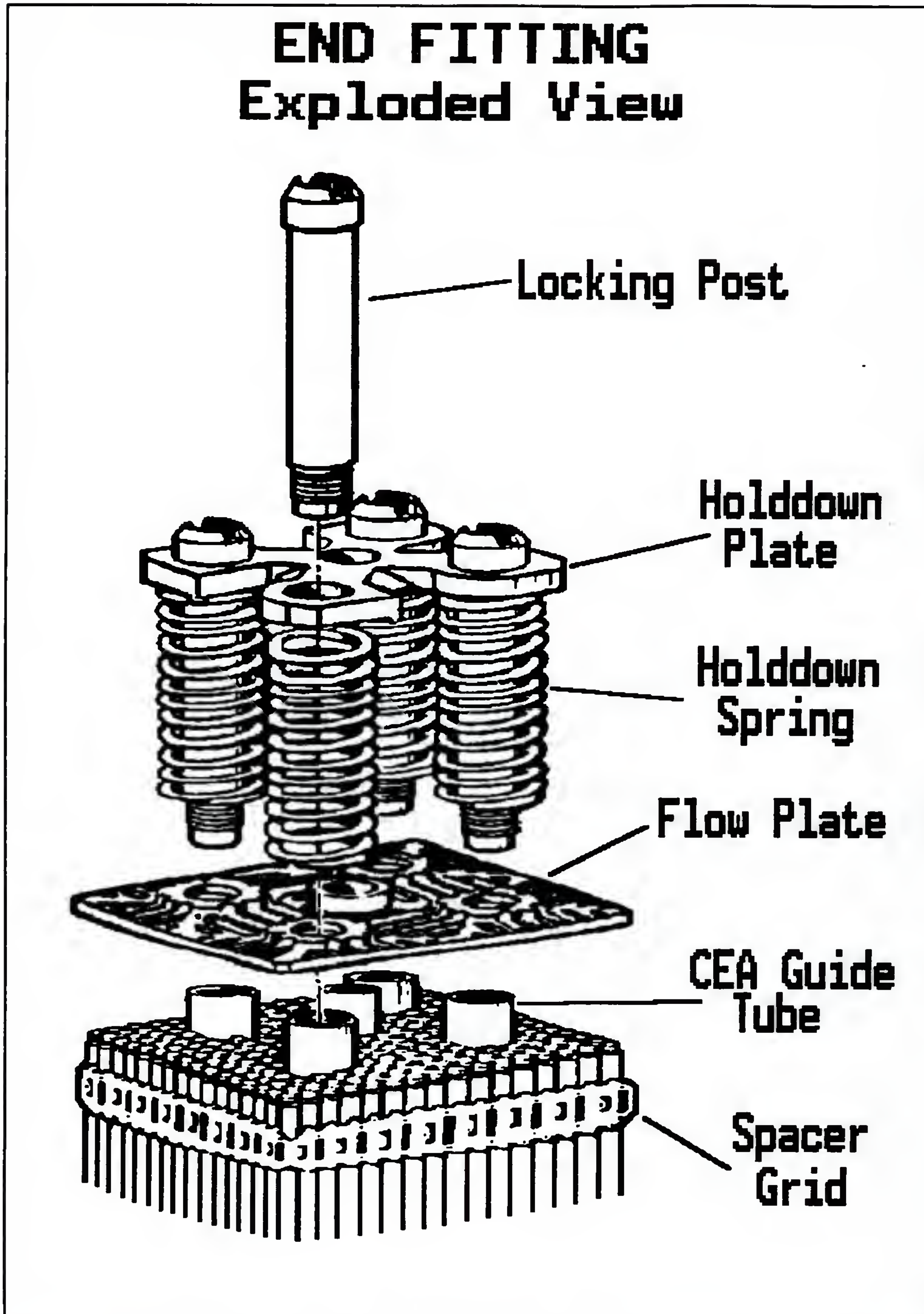

Figure 1. Exploded view of a Combustion Engineering Upper End Fitting on a PWR fuel assembly.

part of the spent fuel assembly, but when rod consolidation is used, these components are no longer associated with the fuel rods and must be handled separately. The empty assembly skeleton as a whole will most likely classify as GTCC LLW as will many of the individual components which make it up. However, due mainly to differing materials of fabrication, some of these components may not be GTCC, so with proper hardware sorting, the quantities of GTCC LLW, i.e. waste that must go to the Federal Repository, could be minimized. Proper classification of these hardware elements is one of the goals of this dissertation and is discussed in greater detail later in the "Domestic Hardware Analysis" section of this chapter.

Another frequently overlooked waste stream which has an impact on both the spent fuel storage problem at utility reactor sites and on the repository planning is Non-Fuel Assembly hardware. This waste stream is just one portion of what utilities consider operational waste, the waste generated through the daily operations of a nuclear plant. NFA hardware includes all the hardware components that are related to the reactor core and/or assemblies, but are not considered to be or to contain fuel. These include, but are not limited to, burnable poison rods, control rods, neutron sources, and incore detectors. Figure 2, Figure 3, and Figure 4 illustrate some of the types of NFA hardware which must be considered. These components have operational lifetimes associated with them and must be replaced

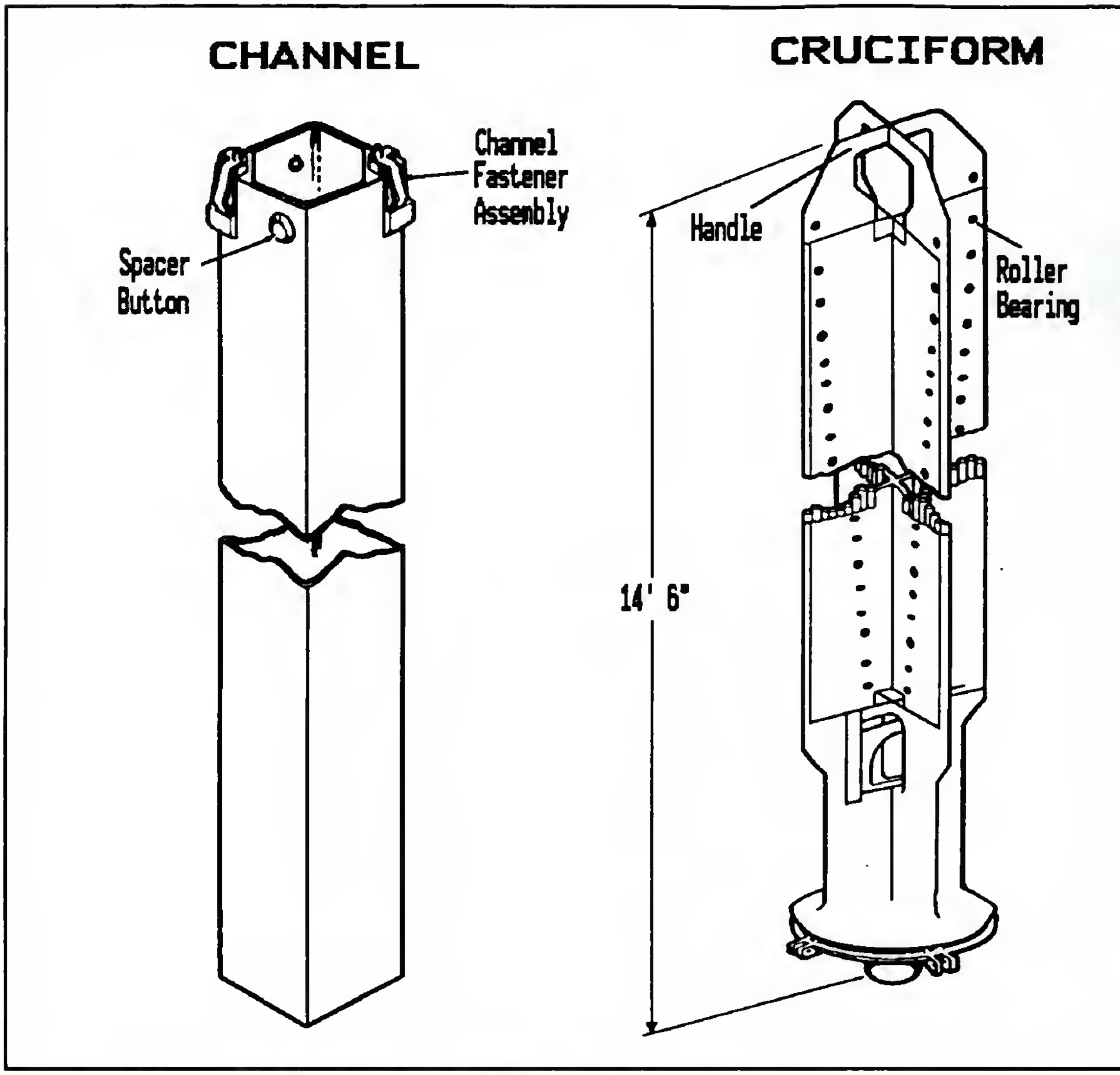

Figure 2. BWR Non-Fuel Assembly Hardware.

periodically. In most cases, the discarded hardware is stored in the spent fuel pool pending disposal, either loose or within void spaces in spent fuel assemblies, i.e. in empty guide tubes. Control rods in particular are often stored within the assemblies and many utilities expect them to be disposed of in this manner. Two problems exist with this approach. First, the dimensions used in current shipping cask designs are insufficient to allow for anything

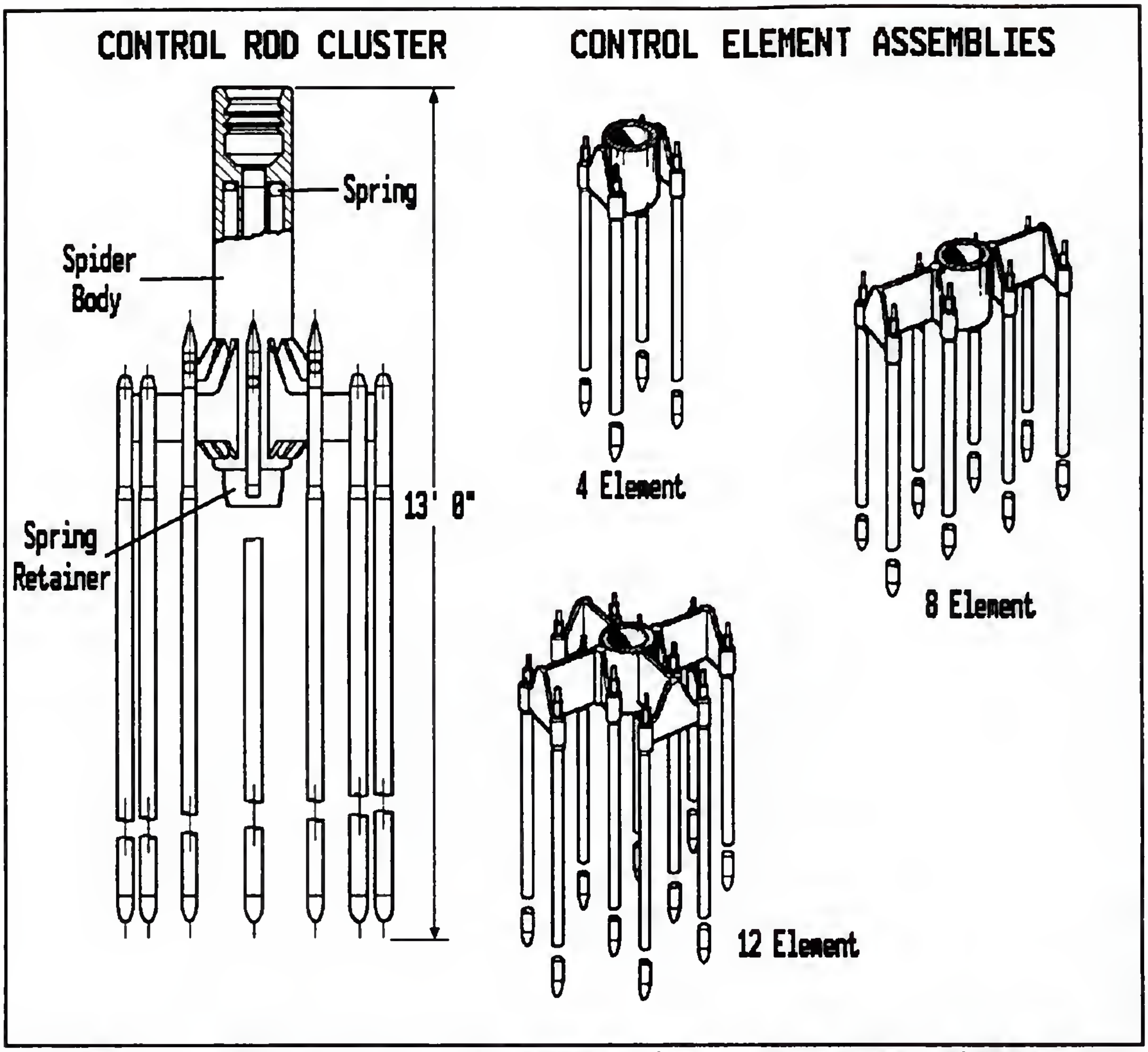

Figure 3. PWR Control Rod Assemblies. The left diagram illustrates a Westinghouse Control Rod Assembly while the right diagram shows three different configurations used for Combustion Engineering Control Element Assemblies.

larger than the spent fuel assemblies. Control rod assemblies, when inserted into fuel assemblies, increase the assembly length by several inches and would prevent the shipping cask from closing. To a lesser extent, spent fuel consolidation also poses a problem for hardware storage. Since consolidation removes the space available for storage

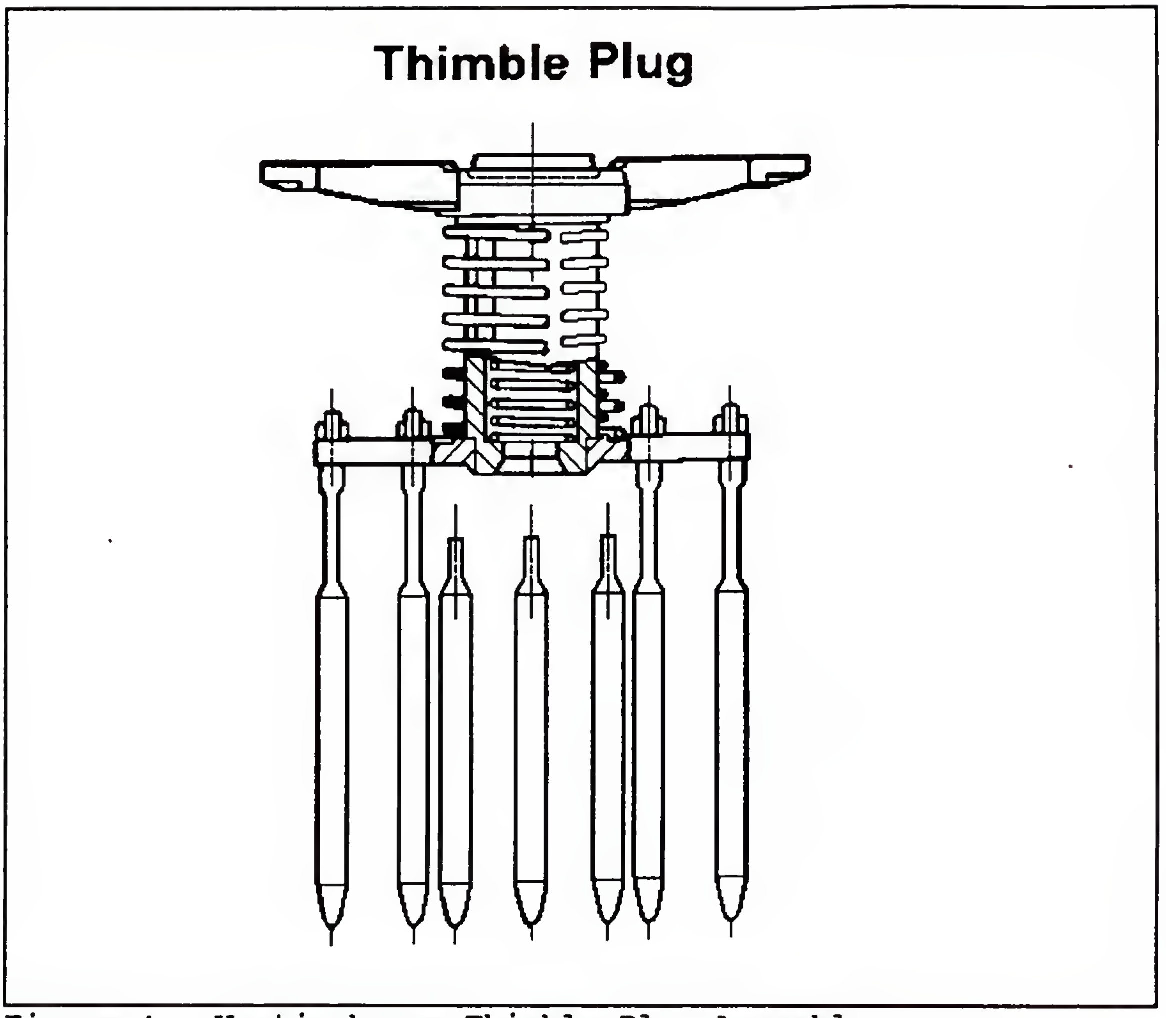

Figure 4. Westinghouse Thimble Plug Assembly.

within the assemblies, alternative storage space must be provided, usually at the expense of spent fuel pool space.

Regardless of the status and extent of consolidation, NFA hardware must be taken into account as a separate waste stream needing final disposal. Under the terms of the "Standard Contract for Disposal of Spent Nuclear Fuel and/or High-Level Radioactive Waste" entered into by the DOE and the individual nuclear utilities, the DOE is obligated to

accept for disposal all non-fuel components. Specifically, the contract states that

> non-fuel components including, but not limited to, control spiders, burnable poison rod assemblies, control rod elements, thimble plugs, fission chambers, and primary and secondary neutron sources, that are contained within the fuel assembly, or BWR channels that are an integral part of the fuel assembly, which do not require special handling, may be included as part of the spent nuclear fuel delivered for disposal pursuant to this contract.[20]

The contract then proceeds to state that other components which do not meet these guidelines will be accepted as non-standard fuel. The waste classification of this hardware is unclear, but is certainly either Class C LLW or GTCC waste. Resolution of this matter is another goal of this dissertation and is discussed throughout the remainder of this work.

In order to plan and implement the disposal of the NFA and SFD hardware waste streams properly, several pieces of information are necessary, including the hardware's physical and radiological characteristics. The hardware's length, width, and susceptibility to crushing determine the volume that this waste will occupy. The weight of the components is important for transportation planning and determining crane loads at the disposal site. The initial materials of construction, and the isotopic composition of those materials, can be used to predict the radioisotope concentrations after irradiation. However, the initial concentrations of some isotopes exhibit considerable variations and are often not measured at all, particularly

in the case of trace elements like niobium, thus making it difficult to predict the future radiological characteristics of these isotopes. Alternatively, in the absence of detailed isotopic compositions, direct or indirect measurement of the radioisotopes of interest can be performed after irradiation. Whatever the process used, these radioisotope concentrations are necessary for the accurate determination of the hardware waste classification according to 10CFR61. The curie content of the hardware, either by direct measurement or by calculation, is also important for shielding purposes at all stages of disposal. The most important datum, however, the quantity of individual hardware items to be disposed of, is also the most difficult to determine.

To predict the number of NFA hardware elements for disposal accurately requires information that is not easily located in the open literature. First, the types and number of NFA hardware components that are used at each reactor must be determined. These values vary widely from one reactor to another due to reactor design changes and differing utility operational practices, as well as differing reactor vendors. NFA hardware, like reactor fuel assemblies, has also evolved over the life of the plant, so that the initial configuration may bear little resemblance to the current configuration. Hardware lifetimes represent another important facet of the problem. Hardware vendors can provide design lifetimes for all of the hardware that

they manufacture, but the utility of this information is questionable or at least in need of verification. In actual practice, manufacturers' proposed lifetimes are frequently not met either through premature component failure or through preventive replacement, i.e. purposely replacing the component before its design lifetime elapses. Additionally, the changing needs of the reactor may cause the use of some components to be discontinued which may a) cause some of these components to be discharged earlier than expected and b) result in fewer total components discharged than expected. For example, at the Prairie Island Nuclear Generating Plant near Minneapolis-St. Paul, Minnesota, "all use of BPRA [burnable poison rod assemblies], thimble plugs, and source assembly inserts has been discontinued."[18] Many hardware lifetimes are also given in terms of Effective Full Power Days, and therefore depend on the operational history of the reactor. Finally, to complicate the issue further, many reactor sites have shipped some or all of their NFA hardware components directly to LLW sites for disposal. Whereas this policy helps to relieve the anticipated burden on the FWMS, it makes the determination of how much will require disposal in the future that much more difficult.

On a single reactor basis, quantities of SFD hardware are usually somewhat easier to predict. The quantity of SFD hardware is directly related to the number of assemblies which are consolidated, which is dependent upon both the utility and the specific reactor site. The number of

assemblies that can be consolidated is strictly limited to the number of assemblies stored and generated on-site, barring transshipment from other reactors. Each assembly consolidated will produce one assembly skeleton of SFD waste. However, even when given the quantity of assemblies consolidated, SFD hardware quantities could still show a considerable variance based on the fuel assembly type. Seventy-nine fuel assembly types have been identified by the CDB,[21] and each type has its own specific hardware quantities. There is a significant difference between the SFD hardware weights of a BWR assembly and a PWR assembly and, in general, between any two PWR or BWR assemblies. Typical total weights of all SFD hardware components within a PWR assembly range from 24.6 kilograms to 44.0 kilograms per assembly, while BWR assembly hardware weights range from 8.0 kilograms to 16.8 kilograms per assembly.[22] As can be seen from these figures, BWR assemblies have roughly one-third the SFD hardware, by weight, of PWR assemblies, which is as expected due to the smaller size of BWR assemblies. Since no utilities are currently pursuing fuel rod consolidation, the only SFD hardware currently of concern is that generated by the consolidation demonstrations. However, if more utilities decide to utilize consolidation, these quantities could become almost as difficult as NFA hardware quantities to predict.

As a portion of the effort directed toward the development of the repository, waste characterization has

become a major research area. The majority of the characterization effort has been directed toward HLW and SNF, so there is incomplete information on NFA and SFD hardware. Even reprocessing studies which produce both SFD hardware and cladding hull wastes generally only include a brief mention of this hardware waste, when it is mentioned at all. There has been an increase in interest in this area recently, however, so information has become more available. What follows is a review and analysis of that information.

Characteristics Data Base

The first significant source of data to be developed which dealt with NFA hardware and SFD hardware was the Characteristics Data Base (CDB). The CDB was developed in 1987 by Oak Ridge National Laboratory (ORNL) to serve as a standard data source for information on all forms of waste which may be disposed of in the federal repository.[23] In the summer of 1988, the author performed an analysis of the CDB for his practicum research at ORNL. A classification scheme for LWR fuel assemblies resulted from this work.[24]

The CDB is composed of five user-oriented, menu-driven data bases which can be used on any IBM PC or compatible computer. The data bases contain information on the physical and radiological characteristics of the radioactive wastes which are expected to be emplaced in the Federal HLW Repository for final disposal. The five data bases which comprise the CDB are 1) the LWR Assemblies Data Base, 2) the

LWR Radiological Data Base, 3) the LWR Quantities Data Base, 4) the LWR NFA Hardware Data Base, and 5) the High-Level Waste Data Base. General descriptions of the contents of these data bases are provided in Table 6. Only two of these data bases are directly applicable to this work, the LWR Assemblies Data Base and the LWR NFA Hardware Data Base.

Table 6. Summary of the contents of the five data bases of the Characteristics Data Base.

Data Base	Contents
LWR Assemblies	Physical descriptions of intact fuel assemblies (dimensions, weight, number of fuel rods, materials, etc) for 58 distinct assembly types at time of publication; Radiological properties (curie content, isotopic content, and heat generation rate) and limited physical properties (weight and location) of SFD hardware elements.
LWR Radiological	Radiological properties (composition, curie content, and heat rate) of intact fuel assemblies as a function of assembly type, burnup, and decay time.
LWR Quantities	Historical inventories and projected quantities of discharged LWR fuel assemblies based on Energy Information Administration data and predictions.
LWR NFA Hardware	Physical descriptions (dimensions, weight, materials, etc) and radiological properties (curie content, heat rate, composition) of NFA hardware by vendor, hardware type, and reactor.
High-Level Waste	Physical descriptions (chemical and isotopic compositions, canister type, and age) of current HLW inventories for both commercial and defense wastes; General characteristics of immobilized waste forms based on baseline solidification programs.

The data bases were originally developed using dBase III+, then the menus were written and compiled separately using a dBase compiler called Clipper. When using any of the five data bases, it is the compiled version that is being used. Use of the menu-driven files eliminates the need for any knowledge of the dBase program, but as a direct consequence, limits the amount of data which can be extracted from the individual dBase data files which comprise the menu-driven data bases. Accordingly, for the purposes of this work, the individual data files were accessed directly to take maximum advantage of the available resources.

Several diverse sources of data were used to develop the data bases of the CDB, but only two types of sources were important to the LWR Assemblies Data Base and the LWR NFA Hardware Data Base. Both of these data bases derived their physical properties data from materials provided by the original fuel vendors and their radiological information from the ORIGEN2 computer code. The information on the physical properties of the assemblies and the related hardware was sought from the vendors of the original components. Individual contracts were entered into between ORNL and each supplier including GA Technologies, Babcock & Wilcox, Combustion Engineering, Westinghouse, and Advanced Nuclear Fuels Corporation (formerly Exxon) under the terms of which the corporations provided all available information on all the fuel and reactor hardware that they had ever

manufactured and/or sold.[25] The quality and quantity of information provided by each corporation varied considerably resulting in very inconsistent records within the CDB. In addition, General Electric (GE) declined to enter into a contract, so very little information on GE fuels or hardware is included in the CDB. However, the CDB represents one of the only sources of information for this data and, in spite of its deficiencies, is by far the largest compilation of this nature made to date.

Both the LWR Assemblies Data Base and the LWR NFA Hardware Data Base also include an extensive file containing radiological information which can be applied to the hardware elements. The radiological data was provided by the ORIGEN2 computer code, ORIGEN2 being an acronym for Oak Ridge Isotope Generation and Decay code Version 2.[26] A detailed model of the specific reactor conditions is required for each calculation, and as the code was originally developed to predict the isotopic content of fuel assemblies after irradiation, the most accurate models available are for the core region. Therefore, the information for hardware in the fueled region is more accurate than that for hardware in the top, bottom, or gas plenum regions. At the time of publication of the CDB, efforts to improve the modeling of the regions immediately outside the active core region were ongoing.[27] Furthermore,

> the flux decreases significantly in the two zones adjacent to the core zone [while] the effective

> cross sections outside the core zone increase up to 570%, depending on the element (Co, Ni, Nb, or N), the zone, and the reactor type. This increase is presumably due to resonance and a higher fraction of thermalized neutrons outside the core zone.[28]

These changes give rise to scaling factors used to correct the values calculated for these regions. These scaling factors are discussed in greater detail within the context of the current Pacific Northwest Laboratory research (see the "Other Sources" section of this chapter). With due consideration for the foregoing, the data from ORIGEN2 is used within the data bases to help estimate the waste classifications of the assorted hardware components.

Details of the hardware information contained within the CDB can be found within the data bases and, to a lesser extent, within the hardcopy report which is associated with it. There are 78 assembly types, 39 SFD hardware types, and 95 NFA hardware types listed within the CDB. In the case of SFD hardware, the hardcopy report includes general information on typical hardware elements, but the data base does not contain more precise information on the physical properties of the hardware. Where information on the SFD hardware is available, it is restricted to the hardware's general type, weight, material of construction, and vertical location within the core. For example, the 39 hardware types specified in the LWR Assemblies Data Base do not truly represent 39 different hardware items. Five of these records represent grid spacers with the only difference between these records being their vertical location on the

assembly. Overall, the level of detail available on SFD hardware is very low, even in comparison to the information available on NFA hardware.

The SFD hardware information is a portion of the LWR Assemblies Data Base, which consists of 19 dBase data files. Most of these files, however, contain information on the LWR fuel assemblies, so only five of them were used for this work. Details of the five files are as follows:

1) HARDWARE.DBF: Contains 310 records linking SFD hardware elements to individual assembly types.

2) MATERIAL.DBF: Contains 354 records listing the material(s) of construction and weight of each hardware element.

3) MATNAME.DBF: Contains 28 records which convert the material code given in the MATERIAL.DBF file into a material name and density.

4) SFDNAME.DBF: Contains 40 records which convert the SFD code given in the HARDWARE.DBF file to hardware names and also to the irradiation zone where this hardware resides.

5) INDUCED.DBF: Contains 26,979 records which provide the radiation characteristics for all of the SFD hardware elements.

The INDUCED.DBF file is particularly large due to the number of cases it contains. In order to facilitate transferring this file from one computer to another, a smaller version of this data base containing only the 1474 records needed by the Hardware Waste Expert System (HWES) was developed.

For NFA hardware elements, the 95 types identified in the CDB are broken down as follows: 7 BWR fuel channels, 23 burnable poisons, 26 incore sources, 9 incore instrumentation thimbles, 28 control assemblies, and 5 guide

tube/orifice plugs. Table 7 shows what NFA hardware information is included for each of the reactor vendors. Additionally, hardware that is listed as "included" was presumably complete when the data base was created in 1987, but as no updates have been completed since then, additional hardware types may have been subsequently introduced.

The NFA hardware information is contained in the LWR NFA Hardware Data Base, in a group of 27 dBase data files. Whereas all of the information contained in these files relates to NFA hardware, not all of the information was relevant to this dissertation, so only 13 of them were used. Details of the 13 files are as follows:

1) CHANNELS.DBF: Contains 7 records providing specific information on BWR fuel channels.

Table 7. NFA hardware information included within the Characteristics Data Base.

	Included	Not Included
Babcock & Wilcox	Guide Tube Plugs Control Assemblies Neutron Sources Burnable Poisons	Incore Instrumentation
Combustion Engineering	Incore Instr. Control Assemblies Neutron Sources	Guide Tube Plugs
General Electric	BWR Fuel Channels	Incore Instrumentation Control Blades Burnable Poison Curtains Neutron Sources
Westinghouse	Guide Tube Plugs Control Assemblies Neutron Sources Burnable Poisons	Incore Instrumentation

2) CLIMIT.DBF: Contains 8 records listing the 10CFR61 Class C limits for isotope concentrations in activated metals.

3) COMPOSED.DBF: Contains 444 records which indicate the materials of which the various NFA hardware elements are composed.

4) CONTROL.DBF: Contains 25 records which provide specific information on control assemblies.

5) INSTRMNT.DBF: Contains 9 records which provide specific information on incore instrumentation.

6) MATNAMES.DBF: Contains 46 records for the conversion of the material codes provided in the 6 hardware data files into specific material names and densities.

7) PARTNAME.DBF: Contains 96 records which convert the part codes given in the 6 hardware data files into specific hardware names and weights.

8) PLUGS.DBF: Contains 5 records listing specific information on guide tube plugs.

9) POISONS.DBF: Contains 23 records with specific information on burnable poisons.

10) PWRPLANT.DBF: Contains 1092 records which link the various hardware types to the individual reactors.

11) RCTNAMES.DBF: Contains 126 records listing all of name of the reactors which are represented within the CDB.

12) SOURCE.DBF: Contains 26 records listing specific information on incore sources.

13) RADDATA.DBF: Contains 26,086 records which are used to provide all the radiation characteristics for the various hardware elements.

The RADDATA.DBF file, like the INDUCED.DBF, is extremely large, so a reduced version of the file was developed which contains only those cases necessary to the functioning of the HWES.

The CDB serves to illustrate both the large quantity of necessary data for complete hardware characterization and the still incomplete nature of that data. Information on GE hardware is virtually non-existent while information from the other vendors does not include all hardware categories. Also, the information on the hardware included in the data base has several gaps. Many records do not include complete weights, dimensions, and materials of composition, all of which are important for waste classification and packaging purposes. More importantly, however, the most commonly absent data items for all hardware entries are the hardware lifetime, the reactors at which the hardware is used, and the number of components used at each of these reactors. Of the 95 hardware records, 59 do not have lifetimes listed, nor can lifetimes be readily assumed for these components. Information connecting specific hardware components to specific reactors is particularly difficult to locate, because the utilities do not typically refer to their hardware by the same nomenclature used by the vendors or by the developers of the CDB. In the case of the Westinghouse information, no data was provided linking specific hardware types to specific reactors. The creators of the CDB desired to be conservative with the given data, so no restrictions were created which did not already exist. Accordingly, any hardware component which could possibly be employed at a given reactor is assumed to be used at that reactor. As a result, each Westinghouse reactor has between 14 and 19

hardware records assumed to be associated with it, a number which is far higher than that for reactors where hardware was specifically associated. These records are listed as "assumed" by the CDB to distinguish them from records for which better information is available, but the numbers are nonetheless misleading.

In spite of these difficulties, the CDB has proven to be a very useful data source. The information provided for Combustion Engineering and Babcock & Wilcox reactors is substantially complete and can be used to estimate values for Westinghouse reactors. In terms of hardware volumes, the major PWR NFA hardware categories, i.e. Burnable Poison Rod Assemblies and control rods, are included in the data base. The incore instrumentation and guide tube plugs which are not described are expected to represent only a small fraction of the overall hardware waste volume (see "Program Results," Chapter 4). For BWRs, the only major volume of hardware not described is the control blades; the CDB does describe the fuel channels, the NFA hardware waste category with the largest anticipated volume. Thus, while additional data is still required, the CDB provides a starting point for future data gathering efforts. The CDB was used as the primary data source for this work and the development of the HWES.

Utility Survey

Among all the possible sources of information on NFA and SFD hardware, the source which is most likely to have the desired information are the nuclear utilities. All NFA hardware waste has ultimately been generated by the nuclear utilities, and most consolidation pilot projects were carried out in direct cooperation with a nuclear utility. Accordingly, any existing records which detail how many control rod assemblies have been discharged from a reactor, for example, are most likely to be in the possession of the utilities. Additionally, the utilities should also be able to specify what lifetime was achieved for the hardware, where it is being stored, what effect if any, hardware storage has on spent fuel storage, and a host of other details. Therefore, a survey of the nuclear utilities was developed as a portion of this work.

The original survey design had two purposes: 1) to provide numbers to validate (or correct) the results of the HWES and 2) to gather additional information about the NFA hardware elements. At first glance, the first goal appeared straightforward since the desired information consisted of a series of numbers which were presumably readily available. Upon later examination, however, it became apparent that the desired comparisons were not as easy as originally anticipated. First, a clear distinction was needed between how many elements had been discharged and how many were currently in storage as several utilities have already

disposed of various NFA hardware elements at LLW sites. Second, comparison with the results of the HWES proved to be difficult at best. The results generated by the Expert System are based on the information available in the CDB which frequently turns out to be either too sparse or too detailed. The problem with the Westinghouse hardware information discussed in the previous section provides a good example. Each Westinghouse reactor listed in the CDB (56 reactors in total) is listed as having between 14 and 19 different NFA components, which are too many entries. Conversely, since these associations are assumed and not based on known facts, no values are provided indicating how many of each type of element are used at a reactor. Here, information is too sparse. While the general information in the CDB is sufficient for the HWES, the lack of detailed information limits the usefulness of the utility survey.

The second goal, to gather additional information, suffers from another problem in comparing data to CDB information. Any information gathered must be matched with an item from the CDB to improve the data base. All hardware entries within the CDB have specific names as provided by the original vendors, or where none were provided, by the CDB developers. However, the test utility responses did not generally use any names at all and, when names were used, they did not match the hardware names listed in the CDB. On the other hand, the CDB contains almost no data on BWR hardware, so any information that can be uniformly

categorized would be an improvement. Additionally, responses providing actual hardware lifetimes would prove useful as the lifetimes given in the CDB are theoretical lifetimes for each hardware type. Information on how the hardware is currently being stored, how much has been disposed of, and how it is affecting spent fuel storage would also be helpful in gauging the extent of the problem represented by the hardware. Hence, a wide variety of information was believed to be available from the utilities.

A survey was drafted for distribution to the utilities. The survey essentially comprised three pages consisting of a one page table for information about NFA hardware types, quantities, and lifetimes; one page for general NFA hardware storage information; and one page for general SFD hardware information. The survey was completed in late August 1989 and was ready to begin distribution by late September 1989. Before distribution of the survey could begin, however, OCRWM indicated that they were also planning to perform a survey of this nature, and requested to review the author's survey. The utilities were then consulted by OCRWM and requested that OCRWM, instead of the author, conduct the survey; thus, OCRWM requested that the author's survey be canceled. The author was able to participate in the early development stages of the OCRWM survey, but in general, the original intent of the author's survey was lost along with any control over the survey's execution. The OCRWM survey was duly distributed to the utilities for completion on a

voluntary basis. As of the beginning of September 1990, approximately 50% of the utilities had responded and a distillation of that information was made available to the author.

The original survey had been designed for the general purpose of improving and expanding on the hardware information available within the CDB. The OCRWM survey was designed to gather general NFA hardware information and to act as a test for another future OCRWM survey, and thus did not provide the data in a format consistent with the goals of this work. The problems thus posed to this work were numerous. Since the data which was made available was only a distillation of the utilities' responses, the already limited nature of the data was further emphasized, particularly with regard to comments made by the utilities. More importantly, to improve upon the information in the CDB required that the survey develop direct connections between reactors and hardware types, and between hardware types and hardware characteristics. In the OCRWM survey, at the utilities' request, the data released removed any direct references to reactor names. As a result, no direct comparison of the survey data and the CDB data is possible. The original survey would have established direct interaction between the author and the utilities which could then have been exploited to gather additional information, verify the information already provided, and to clarify any questions which might arise as a result of the data.

Working through the DOE and the complete anonymity required by the utilities precluded this option. Accordingly, the DOE survey resulted in 1) highly incomplete data, 2) no method of verification or clarification, and 3) no practical improvement in the CDB data.

In spite of these difficulties, some interesting conclusions can be drawn from the survey data which further the goals of this work. The responses collected represent 32 Pressurized Water Reactors and 20 Boiling Water Reactors, for a total of 52 reactors. Of the 32 Pressurized Water Reactors, 7 indicated that one or more types of NFA hardware were having detrimental effects on their spent fuel storage capacity. Of these seven, three went further by stating that they had plans to dispose of one or more types of NFA hardware prior to the operation of the federal repository. Additionally, six PWRs had already sent some NFA hardware to be buried at LLW sites, while three other reactors had sent various components to research laboratories for testing. An unknown quantity of these NFA hardware types has been sent to LLW sites by these reactors: control rods, Rod Cluster Control Assemblies (RCCAs), thimble plugs, orifice rods, Burnable Poison Rod Assemblies (BPRAs), neutron sources, incore detectors, incore instrumentation, and retainers. Two reactors indicated that the components which they had disposed of (BPRAs, thimble plugs, RCCAs, and neutron sources) had been crushed, sheared, and placed in metal canisters, one indicated the hardware (BPRAs, orifice rods,

retainers, incore instrumentation, and control rods) had been reduced before shipment, and the other three made no indication of how the hardware had been packaged. Finally, three reactors commented that they expected consolidated fuel and its SFD hardware waste to be removed on the same schedule as intact fuel. Three reactors expect hardware waste from fuel reconstitution to be accepted with the fuel, and two expect BPRAs to be shipped with the fuel.

In contrast to these results, the Boiling Water Reactor responses show a much stronger bias toward immediate hardware disposal. Of the 20 reactors, 12 found that control blades produced adverse effects on spent fuel storage while 2 reactors said the same about Local Power Range Monitors (LPRMs), 2 other reactors said the same about fuel channels, and lastly, 2 other reactors made this comment about neutron sources. While very few found NFA hardware to be a generic storage problem, most intend to dispose of their components on their own instead of waiting for the federal government to take them. Specifically, 17 intend to dispose of control blades, 18 intend to dispose of LPRMs, 8 will dispose of fuel channels, 10 will dispose of neutron sources, and 3 will dispose of poison curtains. Furthermore, these numbers do not give a clear indication of the results, because a large number of reactors did not specify either way. In all of the above cases, the number with plans to dispose of their hardware are in the clear majority of those who expressed their intentions. As for

hardware which had already been disposed of, eight indicated that they had done so and the discarded hardware included the following types: LPRMs, incore instrumentation, control blades, fuel channels, neutron sources, spring clips, and poison curtains. Finally, the BWR comments reflected that one reactor expected consolidated fuel and its SFD hardware waste to be accepted on the same schedule as intact fuel, two intend to ship the fuel channels with the fuel, three reactors store the channels with the fuel, and presumably intend to ship them this way, and one reactor expects to have storage difficulties if it is unable to ship its NFA hardware to LLW disposal.

One of the most important facts learned from this report is that many utilities have in the past and expect to continue in the future to dispose of their NFA hardware at LLW sites. Additionally, the utilities expect (or at least those involved in consolidation activities expect) consolidated fuel and its SFD hardware to be accepted like intact fuel. Some utilities also expect some NFA hardware, most notably BWR fuel channels, to be shipped integral to the spent fuel. While these opinions were expressed by only a small number of the respondents, no dissenting views were expressed either, so there is no reason to assume that these viewpoints are not shared by other utilities. All of these practices could have a significant impact on the FWMS and, as such, should be studied in greater depth in the near future, while the repository is still in its early design

stages. Only such prompt action will prevent greater difficulties later on.

Other Sources

Due to the low disposal priority which has been given to these wastes to date, the number of sources which deal with NFA and SFD hardware are limited. NFA hardware, for the most part, has received no attention and is generally unknown in the literature. Other than the CDB, there are two exceptions. The first exception involves work conducted at the Pacific Northwest Laboratories (PNL) in Richland, Washington. Previous work at PNL included onsite inspection of nuclear utilities to help determine the types of hardware generated at each reactor site. Currently, work is underway which aims to characterize various NFA components, including a BWR control blade. The project will take samples from these components in order to determine the exact isotopic and chemical composition of the hardware materials. The procedures used here will be similar to those used previously for SFD hardware (see the later pages of this section). Results from this work should be available in late 1991.[29]

The other reference was produced by E. R. Johnson Associates, Inc. and attempts to provide a rough approximation of the total quantities of NFA hardware at reactor sites. The study also details the impact which acceptance of NFA hardware will have on the FWMS. Several

key questions are identified which need to be resolved before a more detailed analysis of these impacts can be made. This work is the first to attempt to deal with these points in a comprehensive manner, but by their own admission, is not accurate enough for final design purposes. Further, more detailed work will be required after some of the key issues have been resolved.[30]

SFD hardware, on the other hand, has received a greater degree of attention. For one, SFD hardware can be generated as a result of spent fuel reprocessing and, as such, is occasionally mentioned, but more commonly is merely inferred, in conjunction with fuel pin hulls and their disposal. Such references include no characterization and little actual data.[31,32] The only other source which frequently mentions SFD hardware is literature dealing with spent fuel rod consolidation. In these references, SFD hardware is usually referred to as assembly skeletons and typically does not include detailed characterization. However, since the packing, storage, and disposal of SFD hardware has come to be the pivotal aspect of rod consolidation, there has been an increase in detail available in recent reports.

There are currently two other sources of information on SFD hardware besides the CDB. The first source was produced by Pacific Northwest Laboratory. Before beginning the NFA hardware characterization currently underway, PNL performed similar studies on SFD hardware, the results of which are

now available. The lab took a total of 38 samples from 3 fuel assemblies with burnups ranging from 27,500 to 41,800 MWD/MTU. The samples were subjected to radiochemical analysis to determine the concentrations of the four controlling isotopes (^{14}C, ^{59}Ni, ^{63}Ni, and ^{94}Nb) for LLW disposal of activated metals, as well as ^{60}Co due to its importance in determining the heat rate of the hardware. The samples were also subjected to elemental analysis to determine the concentrations of the parent materials. The study determined that, in general, inconel and stainless steel components were GTCC, while zircaloy components were close enough to the Class C limit to be questionable. In particular,

> in Zircaloy, elemental analyses reflected niobium values from below detectable limits up to several ppm. Curiously, ^{94}Nb was detectable in most of the samples. This is an important result since most items made of Zircaloy are disposed of as low-level waste with no consideration of ^{94}Nb content. Our analyses showed that levels of ^{94}Nb were a significant fraction of 10 CFR 61 limits (17%-97%).[33]

At 17% of the Class C limit the sample is still well below the 10CFR61 limit. However, at 97% of the Class C limit uncertainties in isotopic measurements are sufficient to make disposal as LLW a questionable proposition.

Another result of this project was the development of new scaling factors for use in ORIGEN2 calculations to provide more accurate activation values outside of the active core region. The project used the ORIGEN2 code to predict the expected activation levels in the hardware

samples. The predicted values were compared to the measured values with the intention of producing new scaling factors. Comparison with a similar analysis done at Battelle Columbus Laboratory, however, produced conflicting results. Therefore, the scaling factors were derived based solely on the measured sample values.[34] The resulting scaling factors are 10 to 20 times higher than the initial factors developed in 1978, while ranging from ½ to 5 times the revised scaling factors of 1987. These figures are considered approximations based on the available data with an uncertainty of ±50%, so further work will be required to improve the precision of these results.[35]

The final noteworthy information source on SFD hardware is the work performed by Rochester Gas and Electric (RG&E) in conjunction with their rod consolidation demonstrations. As an extension of the rod consolidation demonstrations, they have performed a considerable amount of work on the classification, treatment, and packaging of SFD hardware. The first finding of this work is that the desired 10:1 compaction ratio for SFD hardware is not being achieved; instead only 5 or 6:1 is being reliably achieved.[36] Second, the report discusses various alternatives for storing the hardware until DOE takes title to it.[36,37] The storage methods discussed are similar to those previously discussed in this work (see the beginning of this chapter).

Of greater interest here, however, are the results of the classification study. Samples were taken from the SFD

hardware generated by the second RG&E consolidation demonstration at Battelle Columbus Laboratory. These samples were subjected to radiochemical analysis and the preliminary results tend to show lower activation levels than the PNL work. Specifically, early reports indicate that all inconel components are GTCC waste, as are Stainless Steel components which have been subjected to a high burnup. Zircaloy components were not found to represent a problem for either storage or disposal.[37] However, it is important to note that the consolidated assemblies from which the hardware samples were taken had only been subjected to a burnup of 20,000 to 22,000 MWD/MTU.[38] As most assemblies receive at least 30,000 MWD/MTU and the industry is trending toward even higher burnups, these measurements are not necessarily representative of the greater majority of SFD hardware.

A computer code, called FuelCalc, was also developed as a portion of this project to provide estimates of the activations levels and waste classification of SFD hardware items. However, the program will not be available for analysis until the final report is released. At that time, a detailed analysis of both the FuelCalc program and the sample analysis methodology will be possible.

Domestic Hardware Analysis

An analysis of the preceding data sources confirms that the disposal of NFA and SFD hardware is not a simple

proposition. To begin with, the utility survey conducted by the DOE indicates that 27% of the responding reactors had disposed of NFA hardware at LLW sites in the past, and 40% intended to do so in the future. Since the DOE has undertaken the responsibility for the disposal of these hardware wastes at some time in the future,[39] for the 40% of the respondents which indicated plans to prematurely dispose of this hardware, the value of the storage space occupied by this hardware presumably exceeds the cost of LLW disposal. The remaining 60% either have no current need to dispose of the NFA hardware or have not committed to doing so in spite of the hardware's detrimental effects upon the reactor's storage capacity. SFD hardware is not currently considered to be a concern as a full-scale rod consolidation campaign has yet to be performed.

A fundamental consideration in this issue is the 10CFR61 waste classification of the NFA hardware. If the waste classifies as GTCC LLW, the only legal disposal option foreseen at this time is eventual emplacement in the future Federal HLW Repository. Waste classifications performed in the past have yielded results which permit NFA hardware disposal as LLW.[40] However, more recent studies such as those examined here indicate that some, if not all, of these hardware elements are not suitable for shallow land burial. A summary of the findings of the sources examined here are presented in Table 8. The results are presented based on the material of construction of the hardware components.

Table 8. A summary of the estimated classification of NFA and SFD hardware components based on the component's materials of construction.

	Low-Level Waste	Greater-Than Class C	Questionable
Characteristics Data Base	None	Stainless Steel Zircaloy Inconel	None
Pacific Northwest Laboratories	None	Stainless Steel Inconel	Zircaloy
Rochester Gas & Electric	Zircaloy	Inconel	Stainless Steel

Components constructed of the materials listed in the "Low-Level Waste" column are considered suitable for shallow land burial by the source in question, while those in the "Greater-Than-Class-C" column are not. For items listed in the "Questionable" column, the reports are not conclusive. Components constructed of these materials may or may not be suitable for shallow land burial depending on the actual initial concentration of ^{94}Nb in the material and the actual burnup experienced by the component. As can be seen from the chart, there are both patterns and inconsistencies to the results. These inconsistencies are resolved in the next section of this chapter.

Hardware Waste Classification

As illustrated by the previous section, the 10CFR61 waste classifications produced by previous researchers for NFA and SFD hardware have shown considerable variation. In

all of these sources, however, the waste classification is primarily determined by the concentrations of ^{63}Ni and ^{94}Nb; the ^{14}C concentrations measured by these sources have not been critical to the waste classification while the ^{59}Ni concentration is usually subordinated to the ^{63}Ni concentration. Since nickel is relatively abundant in inconels and stainless steels, the two nickel isotopes are critical to the classification of hardware components composed of these materials. Zircaloy, however, does not contain sufficient concentrations of nickel for these isotopes to be of concern for waste classifications. Niobium plays a key role in the classification of zircaloy components, as well as contributing significantly to the classification of inconels and stainless steels.

Niobium is considered an impurity in most reactor materials. The American Society for Testing and Materials (ASTM) specifications for zircaloy and stainless steel do not include any guidelines on niobium content in these materials.[41,42] In actual practice, PNL found that niobium concentrations in zircaloy ranged from approximately 40 ppm to as high as 200 ppm, with an average concentration of 127 ppm. In the stainless steel samples, the niobium levels ranged from 7 ppm to 350 ppm, with an average concentration of 109 ppm.[43] Due to the low Class C limit for ^{94}Nb (0.2 μCi/cc), even these "trace quantities may be sufficient for the irradiated material to exceed the Class C limits."[44] In stainless steels, the presence of niobium is usually

overshadowed by the ^{63}Ni concentration. In zircaloys, which do not contain significant quantities of nickel, the concentration of niobium is a critical concern. The concentration of niobium in inconel ranges from 0.7% to 5.5% and is sufficient to guarantee a GTCC classification to any irradiated inconel component.[45,46]

Any attempt to resolve the discrepancies presented by the previous researchers must revolve around the actual initial elemental compositions of the hardware and some approximation of the irradiation history of the component. Therefore, the first assumption made in this analysis is that only stainless steel, inconel, and zircaloy make significant contributions to the Class C limit calculations for NFA and SFD hardware. There are two possible exceptions, but neither should invalidate this assumption. First, BWR control blades contain stellite rollers which typically become very highly activated and would bias the overall waste classification. However, previous waste disposal campaigns conducted on BWR control blades have shown that these bearings are easily removed from the blades, so they will be ignored in this discussion. Second, some neutron sources used in the reactors contain TRU materials and thus may classify as TRU waste. However, if the sources do contain sufficient quantities to classify as TRU waste, then they are not suitable for disposal as either LLW or GTCC waste and are thus beyond the scope of this work. Accordingly, this analysis assumes that source

material quantities are not significant to the waste classification.

The second assumption is that the hardware components are constructed of the materials, and in the proportions, listed in the CDB. While most SFD hardware elements are constructed of only a single material, a given NFA hardware element can be constructed at several, all of which affect the waste classification. Since only three materials are assumed to contribute to the Class C limits, by using the values presented in the CDB, it is possible to estimate the contributions made by these materials for each hardware type. Additionally, since it is allowable to average the concentrations over the total metal volume of the hardware, those materials which do not contribute to the classification can be used to lessen the total concentrations by averaging. Thus, the relative proportions of the contributing and non-contributing materials are assumed to be as specified in the CDB.

The elemental compositions of the materials, specifically the stainless steels, inconels, and zircaloys of which the hardware is constructed, are taken from two sources. The weight percentages of the major constituents are taken from the appropriate ASTM material specifications and are based on these particular grades of the materials: Inconel 625, Stainless Steel 304, and Zircaloy-4. These are the dominant grades of each material used in NFA and SFD hardware. As many of the specifications present a range of

permissible values, the calculations will usually be based on the average of the upper and lower limits. When a value other than the average is used for illustration purposes, the exception will be noted. For those elements which are considered impurities in the materials, i.e. for those elements not listed in the ASTM specifications, the average concentrations found in the samples measured by PNL are used. The physical characteristics of these materials as applied to this work are summarized in Table 9.

The next assumption is that, in most cases, only the concentrations of ^{63}Ni and ^{94}Nb need be analyzed to determine the waste classification. The concentration of ^{14}C is ignored completely by this analysis as this isotope made no

Table 9. A summary of the physical characteristics of the three primary reactor materials studied in this analysis.

Inconel (based on Inconel 625)			
Elements	Concentrations	Variance	Basis
Nickel	58 w/o (min)	-0.45 w/o	spec.
Niobium	3.15-4.15 w/o	±0.15 w/o	spec.
Density = 8.19 g/cc			
Number Density = 8.97×10^{22} nuclei/cc			
Stainless Steel (based on SS 304)			
Elements	Concentrations	Variance	Basis
Nickel	8.0-10.5 w/o	±0.15 w/o	spec.
Niobium	109 ppm (avg)		measured
Density = 8.02 g/cc			
Number Density = 8.52×10^{22} nuclei/cc			
Zircaloy (based on Zircaloy 4)			
Elements	Concentrations	Variance	Basis
Nickel	0.03-0.08 w/o	±0.01 w/o	spec.
Niobium	127 ppm (avg)		measured
Density = 6.56 g/cc			
Number Density = 4.29×10^{22} nuclei/cc			

significant contributions to any of the previous analyses. The ^{59}Ni concentration is only of concern if the ^{63}Ni and ^{94}Nb concentrations are not conclusive, in which case the ^{59}Ni concentration will be estimated for use in a sum-of-the-fractions analysis as described in the "Low-Level Waste" section of Chapter 1. The three isotopes are primarily produced by the following reactions:

$^{58}Ni(n,\beta)^{59}Ni$
$^{62}Ni(n,\beta)^{63}Ni$
$^{93}Nb(n,\beta)^{94}Nb$

For this analysis, these reactions are assumed to be the only sources of these isotopes. The physical and radiological properties of the materials used for this analysis are presented in Table 10. The cross sections presented in Table 10 are for monoenergetic neutrons with an energy of 0.025 eV. Since the average neutron energies in a reactor are actually higher, the actual cross sections in the reactor will be lower; thus, these cross sections will produce conservative results.

Next, to approximate the activation levels achieved in the components, the radiation environment experienced by the hardware must be modeled. First, the reactor core is assumed to be divided into four zones: the top zone, the gas plenum zone, the incore zone, and the bottom zone. The incore zone corresponds to the active fuel region of the core, while the gas plenum zone corresponds to the gas plenum section of the fuel assemblies. The top and bottom zones match the top and bottom nozzles of the fuel assembly,

Table 10. Physical and radiological characteristics of the critical isotopes and their parent materials. (σ_a = absorbtion cross section, $\tau_{1/2}$ = half-life).

Parent Element: Nickel
- Density = 8.90 g/cc
- Number Density = 9.13×10^{22} nuclei/cc
- Isotopes
  - ^{59}Ni
    - Abundance of precursor (^{58}Ni) = 67.9%
    - σ_a = 4.4 barns
    - $\tau_{1/2}$ = 80,000 years
  - ^{63}Ni
    - Abundance of precursor (^{62}Ni) = 3.66%
    - σ_a = 15 barns
    - $\tau_{1/2}$ = 92 years

Parent Element: Niobium
- Density = 8.57 g/cc
- Number Density = 5.56×10^{22} nuclei/cc
- Isotopes
  - ^{94}Nb
    - Abundance of precursor (^{93}Nb) = 100%
    - σ_a = 1 barns
    - $\tau_{1/2}$ = 20,000 years

respectively. The relative sizes of these zones are illustrated in Figure 5. The usage of these zones is consistent with the work performed by ORNL and PNL.

Second, the flux levels experienced by components in each of these regions must be approximated. For these calculations, the incore flux is assumed to be 10^{13} neutrons/cm^2-sec. This value was assumed to be a typical average flux after analyzing several PWR and BWR Final Safety Analysis Reports. Then, the scaling factors developed by PNL are used to approximate the flux in the other regions. The resulting flux levels are also illustrated in Figure 5. In all cases, the flux is assumed

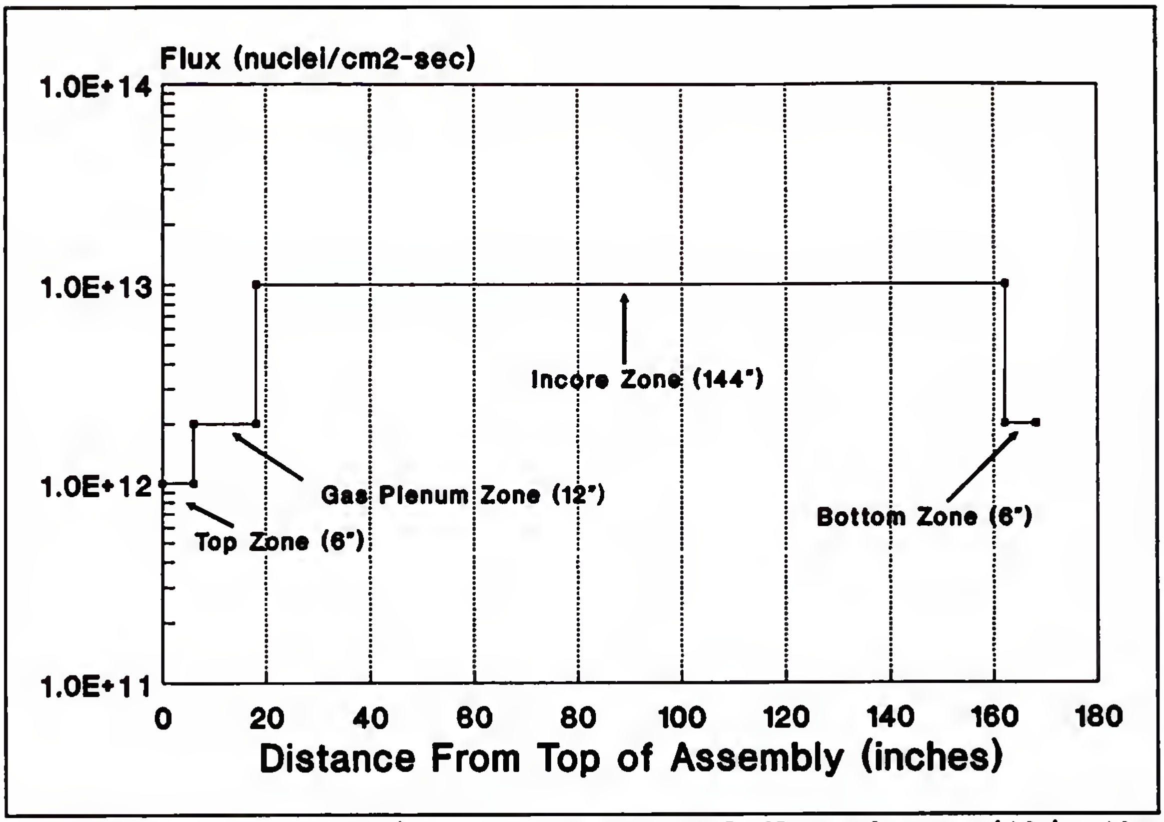

Figure 5. Illustration of the assumed flux shape within the reactor and the size of the four irradiation zones.

to be constant across the core and within a given region. Whereas this is admittedly an oversimplification of the real flux shape, since this analysis is intended to represent average components, this approximation provides an average flux for each region. Furthermore, it is also assumed that the flux is zero outside the core region and when the reactor is shutdown. The only components which are affected by these assumptions are the PWR control rod assemblies, but the effects of this assumption are negligible as will be explained later in this section.

Some assumptions are also made concerning concentration averaging. Concentration averaging is a practice which

allows the measured isotopic concentrations to be averaged over the volume of the waste. In the case of NFA hardware, the concentrations are averaged over the total metal volume of the components, thus excluding any void spaces. This practice produces more uniform waste classifications and lessens the impact of any "hot spots" on the overall classification. The current disposal sites also allow averaging between two or more separate components of the same type, such as between two control rod assemblies. However, based on the assumptions made previously, this analysis is already being performed on an average assembly; therefore, concentration averaging between more than one such assembly produces no changes in the classifications. Accordingly, any concentration averaging performed will be conducted on an individual component basis.

There are a few final assumptions concerning the reactor operational history that must be mentioned. First, one reactor fuel cycle is assumed to be 1.5 years in duration for both PWR's and BWR's. Second, one assembly lifetime is assumed to consist of three fuel cycles, or roughly 4.5 years, again for both PWR's and BWR's. These values represent an idealized PWR operating cycle with one-third of the core replaced each fuel cycle. A BWR operating cycle usually has fuel cycles only one year in length after which one-fourth or one-fifth of the fuel is replaced; thus, a total core replacement occurs every four to five years. For the purposes of this study, this is roughly equivalent

to the PWR cycle, and will be approximated as such. Finally, the reactors are assumed to operate at a capacity factor of 0.688. This capacity factor was the national mean in 1989, and thus is taken as a representative value. The capacity factor is used to convert lifetimes given in units of EFPD to actual years of operation and vice versa.

In order to make proper comparisons with the previous research, approximations of the initial parent element (nickel and niobium) concentrations which will cause the critical isotopes ($^{59}Ni/^{63}Ni$ and ^{94}Nb, respectively) to exceed their Class C limits would be useful. Given the assumptions presented above, it is possible to estimate the activation levels of an isotope in an irradiated material by using the following formula:

$$A=\Phi\sigma_a N(1-e^{-\lambda t}) \quad \frac{decays}{cm^3\text{-}sec} \tag{1}$$

where:

- A = activity (decays/cm^3-sec)
- Φ = neutron flux (neutrons/cm^2-sec)
- σ_a = absorption cross section (cm^2)
- N = number density (nuclei/cm^3)
- λ = isotopic decay constant (years^{-1})
- t = time of irradiation (years)

This formula assumes a constant flux and no decay time after irradiation. Constant flux is one of the assumptions made earlier, and due to the long half-life of ^{94}Nb (20,000 years), the actual decay time of 5 to 15 years is negligible. The decay time has a greater significance to ^{63}Ni since its half-life is only 92 years, but since the values being calculated here are only approximations, the

actual decay will still be of little consequence to this analysis. Also of note is that t represents the duration of the exposure to the given flux, Φ. Accordingly, t is measured in Effective Full Power Years (EFPY), not actual years of operation.

If the activity is known, then equation (1) can be solved in terms of the number density, N, resulting in equation (2). For this analysis, the 10CFR61 Class C limits

$$N=\frac{A}{\Phi\sigma_a(1-e^{-\lambda t})} \tag{2}$$

are taken to be the maximum permissible activation levels, so by using the radiological characteristics presented above (see Table 10), the maximum permissible initial concentrations of the parent elements can be calculated. The resulting values are in terms of nuclei/cm^3, but by comparing the results with the characteristics of the parent materials (zircaloy, stainless steel, and inconel), the concentrations can be converted to units of parts per million (ppm) or weight percent (w/o), as appropriate.

Figure 6 shows the initial niobium concentrations in zircaloy, stainless steel, and inconel which will cause the material to exceed its Class C limit, as a function of irradiation time. Due to its higher atomic number, zircaloy permits the highest concentration of the three materials, while stainless steel and inconel permit almost identical, somewhat lower, concentrations. A comparison of these results with the initial concentrations presented in Table 9

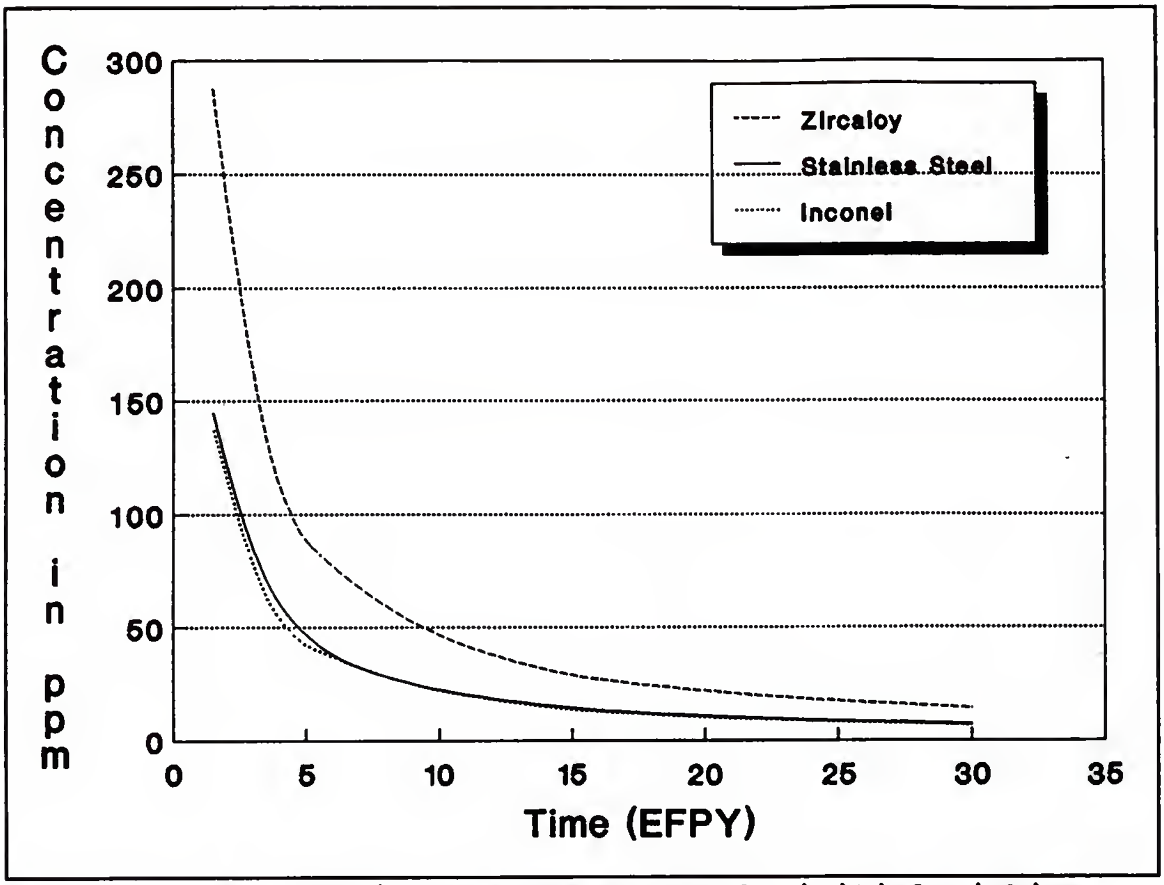

Figure 6. A comparison of the allowable initial niobium concentrations for various irradiation times in zircaloy, stainless steel, and inconel. (Φ=1x10^{13} neutrons/cm^2-sec.)

yields maximum irradiation times based on the material being irradiated. Inconels, which have an average initial niobium concentration of 3.65 w/o (roughly 34,000 ppm), appear to reach their Class C limit almost immediately, certainly in less than 1 year. Stainless steel, with an average initial niobium concentration of 109 ppm, will reach its Class C limit after roughly 2.3 EFPY or 3.3 years of operation. Finally, the 127 ppm average initial niobium concentration in zircaloy will permit this material to be irradiated for about 3.9 EFPY or 5.7 years of operation before reaching its

Class C limit. Table 11 presents a summary of the allowable initial niobium concentrations in NFA hardware based on the hardware's primary material of construction and its theoretical lifetime in terms of actual years of operation. It should be noted that the values presented in Table 11, as well as those in Table 12 which follows, are based on the assumption that the hardware component is constructed solely of the listed material and that the component spends the entire specified lifetime in the reactor core. In cases where these assumptions are not appropriate, the necessary corrections are implemented and explained.

Table 11. The maximum permissible initial concentrations of niobium in NFA hardware as a function of hardware lifetime and materials of construction.

NFA Hardware Type	Lifetime	Mat.	Concentration
BWR Fuel Channels	4.5 yrs 9.0 yrs	Zirc Zirc	140 ppm 70.0 ppm
BWR Control Blades	3 yrs 25 yrs	SS SS	105 ppm 12.6 ppm
Palisades Control Blades	30 yrs	SS	10.5 ppm
Control Rod Assemblies	16 yrs 16 yrs	Inc. SS	18.8 ppm 19.8 ppm
Incore Instrumentation	5 yrs 5 yrs	Inc. SS	60.2 ppm 63.2 ppm
Neutron Sources	14 yrs 16 yrs	SS SS	22.6 ppm 19.8 ppm
Burnable Poisons	1.5 yrs 1.5 yrs	SS Zirc	211 ppm 420 ppm

NOTES: Mat.=Material; Zirc=Zircaloy; SS=Stainless Steel; Inc.=Inconel

The maximum initial concentrations of nickel, based on the activation of ^{63}Ni, are shown in Figure 7. While the allowable concentrations of nickel are much higher than the allowable concentrations of niobium, nickel is also a major constituent of both inconels and stainless steels, so nickel is important to the waste classification of these materials. Both the minimum 58% of nickel in inconel and the average concentration of 9% nickel in stainless steel are above the allowable concentration levels even at only 1.5 years of operation. Only zircaloy does not contain significant

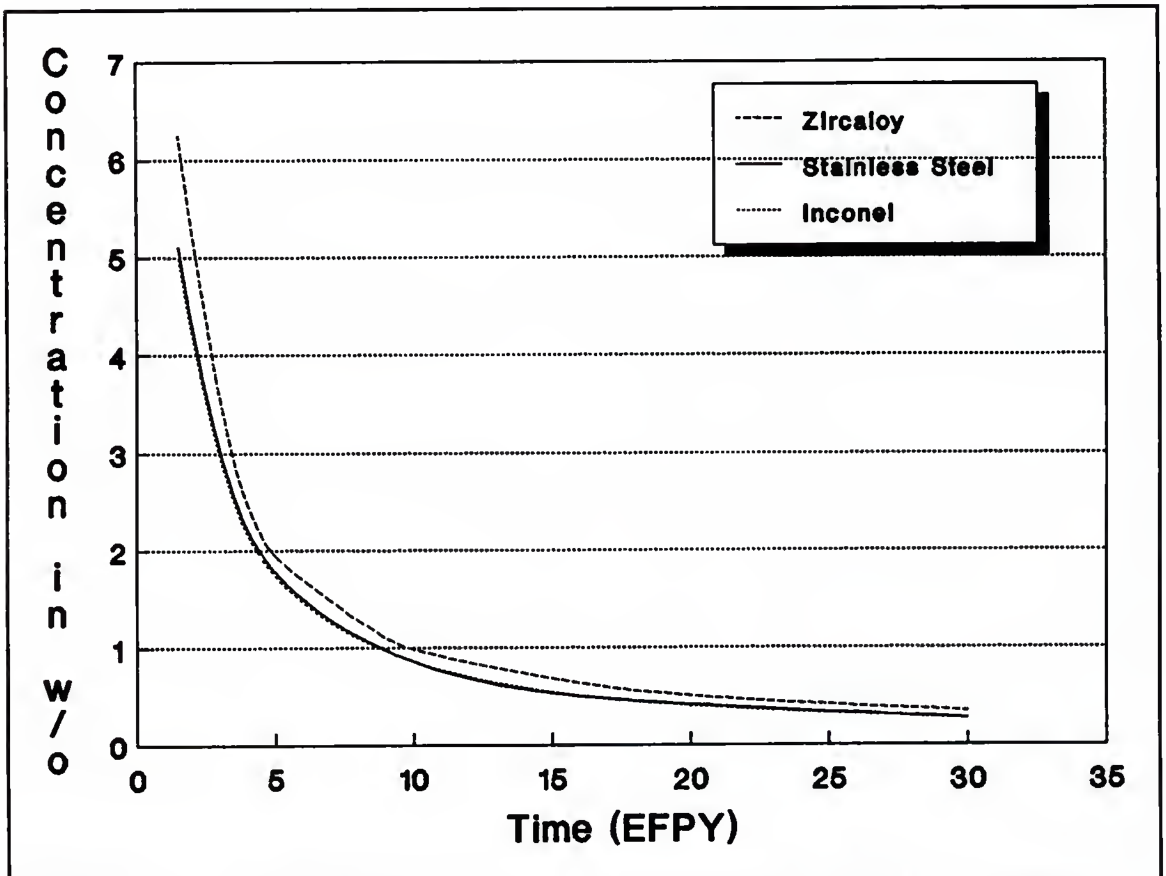

Figure 7. A comparison of the allowable initial nickel concentrations for various irradiation times in zircaloy, stainless steel, and inconel. (Φ=1x10^{13} neutrons/cm^2-sec.)

concentrations of nickel. Nickel is an impurity in zircaloy with a maximum allowable concentration of 0.09 w/o, well below the allowable limit even after 30 years of irradiation. The allowable initial nickel concentrations in NFA hardware based on the primary material of construction and theoretical lifetimes are summarized in Table 12.

Each of the three dominant reactor materials (inconel, stainless steel, and zircaloy) will now be examined individually as they relate to individual NFA hardware types. In each case, the allowable concentrations of the parent elements estimated by equation (2) will be compared

Table 12. The maximum permissible initial concentrations of nickel in NFA hardware as a function of hardware lifetime and materials of construction.

NFA Hardware Type	Lifetime	Mat.	Concentration
BWR Fuel Channels	4.5 yrs 9.0 yrs	Zirc Zirc	15.2% / 3.04% 7.59% / 1.54%
BWR Control Blades	3 yrs 25 yrs	SS SS	18.6% / 3.78% 2.23% / 0.48%
Palisades Control Blades	30 yrs	SS	1.86% / 0.41%
Control Rod Assemblies	16 yrs 16 yrs	Inc. SS	3.40% / 0.71% 3.49% / 0.73%
Incore Instrumentation	5 yrs 5 yrs	Inc. SS	10.9% / 2.20% 11.2% / 2.28%
Neutron Sources	14 yrs 16 yrs	SS SS	3.99% / 0.83% 3.49% / 0.73%
Burnable Poisons	1.5 yrs 1.5 yrs	SS Zirc	37.2% / 7.54% 45.6% / 9.06%

NOTES: % for ^{59}Ni / % for ^{63}Ni; Mat.=Material; Zirc=Zircaloy; SS=Stainless Steel; Inc.=Inconel

to the material specifications presented in Table 9. These results will then be compared and contrasted with the results produced by the previous researchers to produce general hardware waste classifications. When the actual conditions experienced by the components do not agree with the assumptions made earlier, individual analyses will be performed.

Inconel hardware classifications are the least controversial of the three materials. Figure 8 shows the allowable initial niobium concentrations in inconel. After an exposure to 1.5 years of reactor operations, the

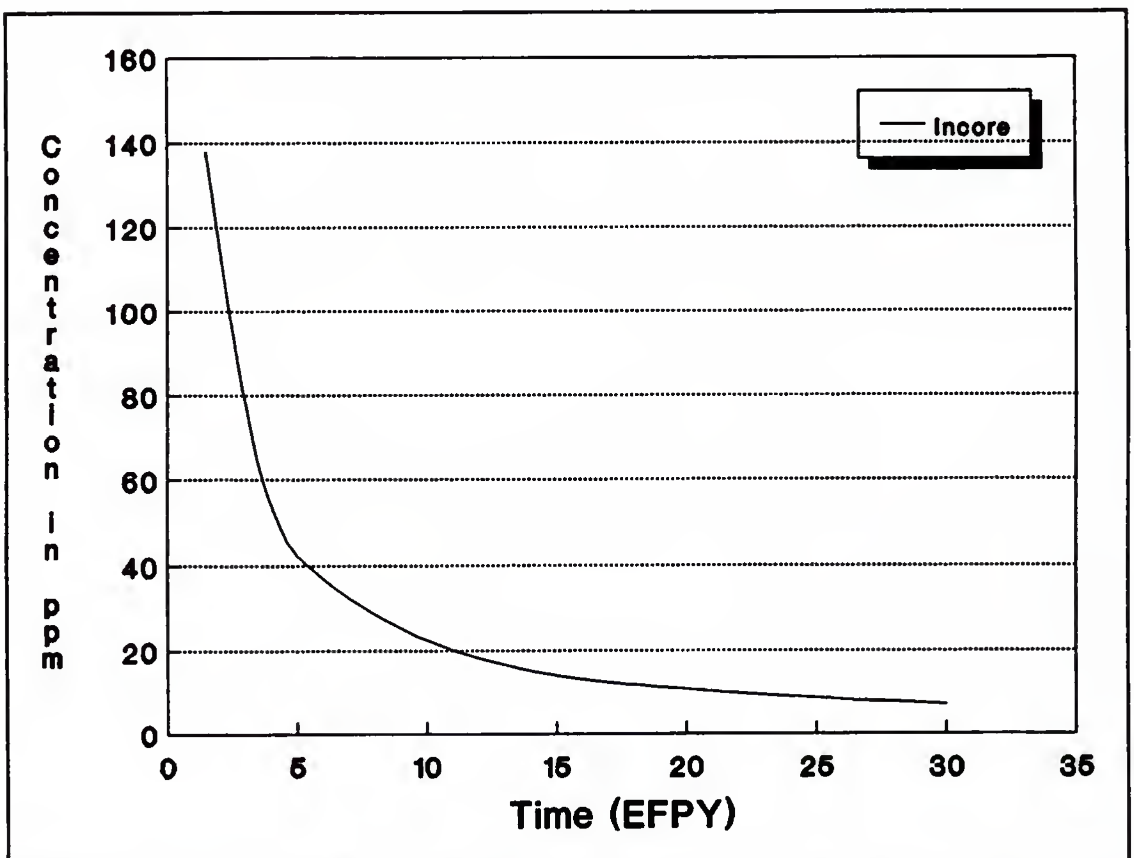

Figure 8. Niobium concentrations in inconel which will cause Nb-94 to exceed its Class C limit as a function of time. (Φ=1x10^{13} neutrons/cm^2-sec.)

allowable initial concentration of niobium is roughly 200 ppm, which corresponds to a weight percentage of roughly 0.02. This value is significantly below the 3-4% of niobium expected in inconel which clearly indicates that ^{94}Nb concentrations in irradiated inconel components are likely to exceed their Class C limit.

The initial nickel concentrations are similarly conclusive. Figure 9 illustrates the initial concentrations of nickel needed to cause each of the two nickel isotopes to exceed their respective Class C limits. Since these curves

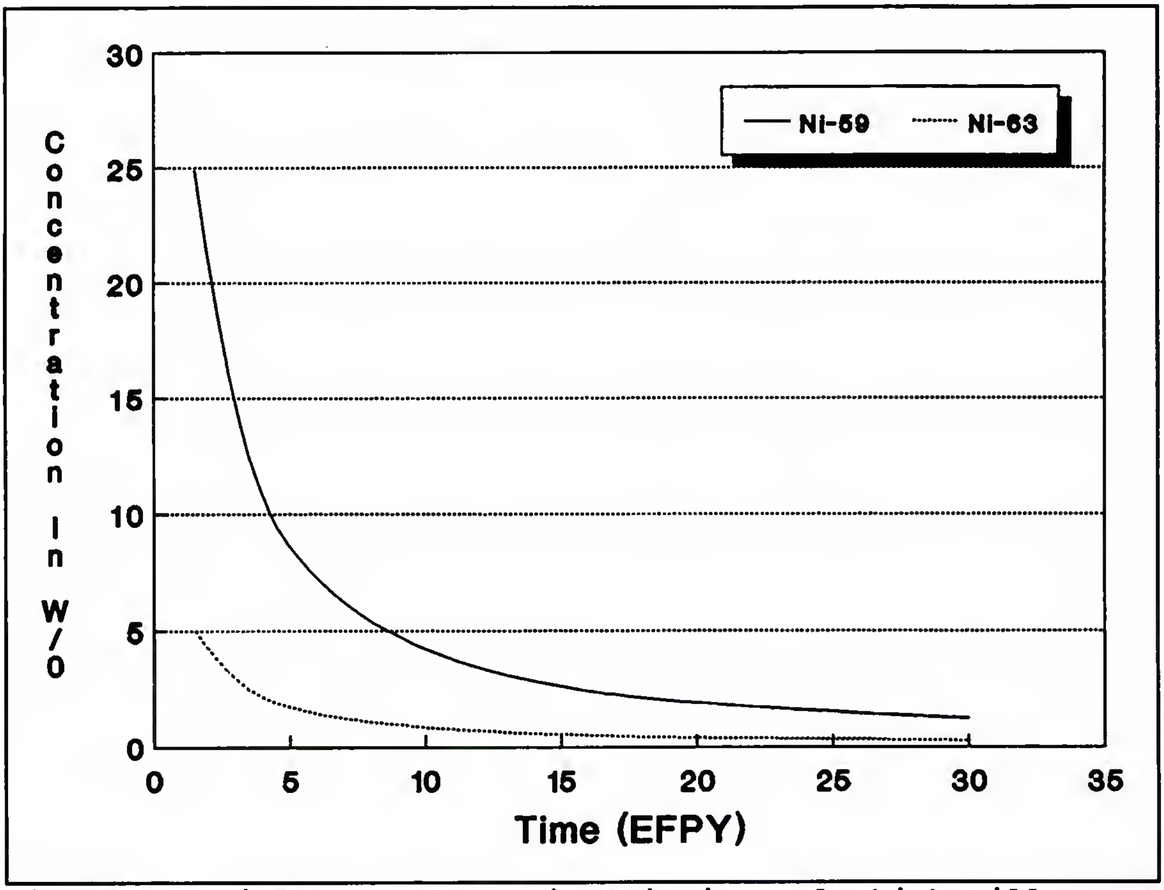

Figure 9. Nickel concentrations in inconel which will cause Ni-59 and Ni-63 to exceed their respective Class C limits as a function of time. (Φ=1x10^{13} neutrons/cm^2-sec.)

take into account the relative abundance of ^{58}Ni and ^{62}Ni (the precursors of ^{59}Ni and ^{63}Ni) in nickel, the lower curve (^{63}Ni) determines the allowable concentrations. Actually, since the Class C limit is determined on a sum-of-the-fractions basis when necessary, the actual limit is 10-20% lower than the ^{63}Ni curve, but this distinction is generally insignificant as will be illustrated. Since inconels contain more than 50% nickel, the actual concentrations exceed the allowable concentrations by at least a factor of 10 for all probable irradiation times. Like ^{94}Nb, ^{59}Ni and ^{63}Ni can both be expected to routinely exceed their Class C limits in any hardware component constructed of inconel. These results are confirmed by all three of the previous researchers. Clearly, "the initial concentrations of nickel and niobium in inconel alloys preclude the possibility that [NFA and] SFD hardware made from inconel alloys will be acceptable for near-surface burial."[47] Thus, components constructed solely of inconel, like many SFD hardware elements, and subsequently irradiated in a reactor will classify as GTCC waste.

For NFA hardware, which is generally composed of more than one material, concentration averaging may alter the waste classification. NFA hardware types which make significant use of inconel include Combustion Engineering Control Rod Assemblies and Incore Instrumentation, which both have inconel cladding, and Babcock & Wilcox Gray Axial Power Shaping Rods, which use inconel as a neutron poison.

The incore instrumentation and the gray axial power shaping rods are both irradiated in the incore zone for their entire lifetime, and the inconel represents 50% or more of the total metal volume in both cases. Based on the material specifications and the allowable concentration curves, ^{94}Nb, ^{59}Ni, and ^{63}Ni are all expected to exceed their Class C limit in these components. The PNL measurements confirmed these findings with actual values several thousand times the Class C limit. Clearly, concentration averaging will be of no practical use in these cases.

For the Combustion Engineering control rod assemblies, the measurements are closer to the limit, but still too high for the rods to classify as LLW. The average inconel classification measured by PNL in the top zone was about 30 times the Class C limit, while the average measured in the gas plenum zone was about 300 times the limit. For the purpose of illustration, this analysis will use the top zone value. Next, the overall control assembly length is about 163", but since the PWR control rods operate fully withdrawn with only the tips being located in the gas plenum zone, only about 18" of the rods (based on the assumed zone dimensions) are actually in the irradiation zones. Therefore, it is estimated that only 11% of the inconel volume is actually irradiated. Based on the assumption of zero flux outside the core, the remainder of the assembly receives no irradiation. Two points should be noted at this time: 1) since the overall length of the assembly includes

the stainless steel spider assembly at the top, the 18 inch length in the irradiation zone actually represents more than 11% of the total inconel, and 2) two-thirds of the irradiated inconel is actually in the gas plenum zone which receives a higher flux than the top zone. Next, the inconel only represents approximately one-third of the total metal volume as shown in Table 13. Finally, the PNL measurements were based on an irradiation time of about 4.5 years. Since the nominal control rod lifetime is roughly 15 years, the activation level experienced should be approximately 3 times higher. Combining all these factors as summarized in Table 13 yields an overall waste classification 3.42 times the Class C limit. Since the assumptions used here tend to produce a low classification, the Combustion Engineering

Table 13. The relative volumes of the materials in a Combustion Engineering Control Rod Assembly and the calculation of the component's waste classification.

Material	Weight	Density	Volume	Material Fraction
Inconel	14.42 kg	8.19 g/cc	1761 cc	31.0%
SS 304	3.63 kg	8.02 g/cc	453 cc	7.9%
Ag-In-Cd	3.90 kg	9.90 g/cc	394 cc	6.9%
Boron Carbide	3.63 kg	2.52 g/cc	3131 cc	55.0%

Total Control Rod Length: 163 inches

Fractional Volume of Irradiated Material:
Top Zone : 18/163 = 0.110 x 0.310 = 0.0342 = 3.42%

Concentration Averaged Waste Classification
(Based on 3 cycles' irradiation):
Top Zone : 0.0342 x 30 = $\underline{1.026}$
1.026

Averaged Waste Classification at Design Lifetime:
1.026 x 10/3 = 3.42 -- GTCC Waste

Control Rod Assemblies are clearly GTCC waste. It should be noted that the stainless steel spider at the top of the assembly receives no significant irradiation. Therefore, if it were separated from the control rods, the spider would qualify for disposal as LLW.

The classification of hardware components constructed of stainless steel requires a more precise examination. The allowable initial concentrations of niobium in stainless steels shown in Figure 10 are very similar to those shown earlier for inconel. As discussed earlier, the PNL study

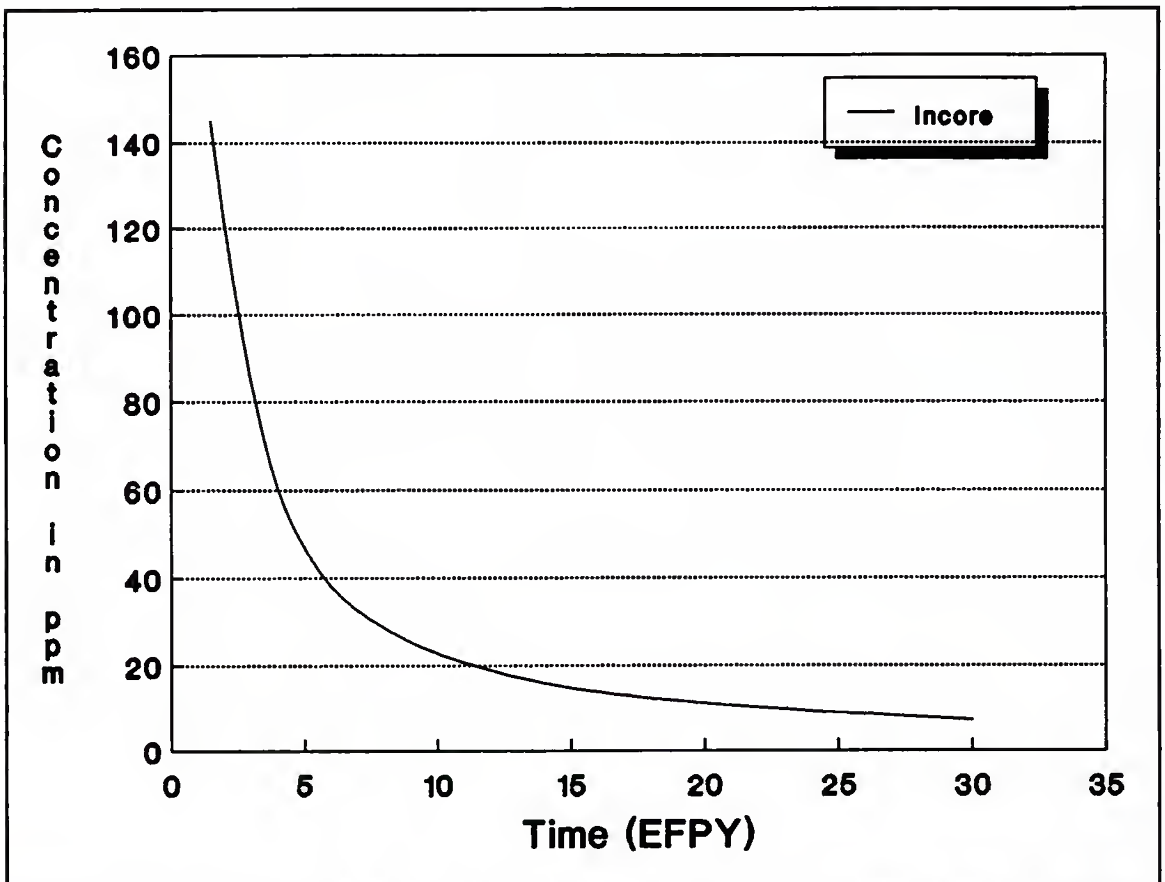

Figure 10. Niobium concentrations in stainless steel which will cause Nb-94 to exceed its Class C limit as a function of time. ($\Phi=1\times10^{13}$ neutrons/cm^2-sec.).

found the average niobium concentration in stainless steel to be about 109 ppm. Thus, the actual niobium concentrations are much closer to the allowable concentrations than was the case for inconel. Additionally, the allowable concentrations also vary with respect to the component's vertical location in the core as shown by Figure 11. The allowable concentrations in the top and gas plenum zones are generally higher than the measured average concentrations, indicating that stainless steel components irradiated in these zones may qualify for disposal as LLW, if the classification was based only on the levels of ^{94}Nb.

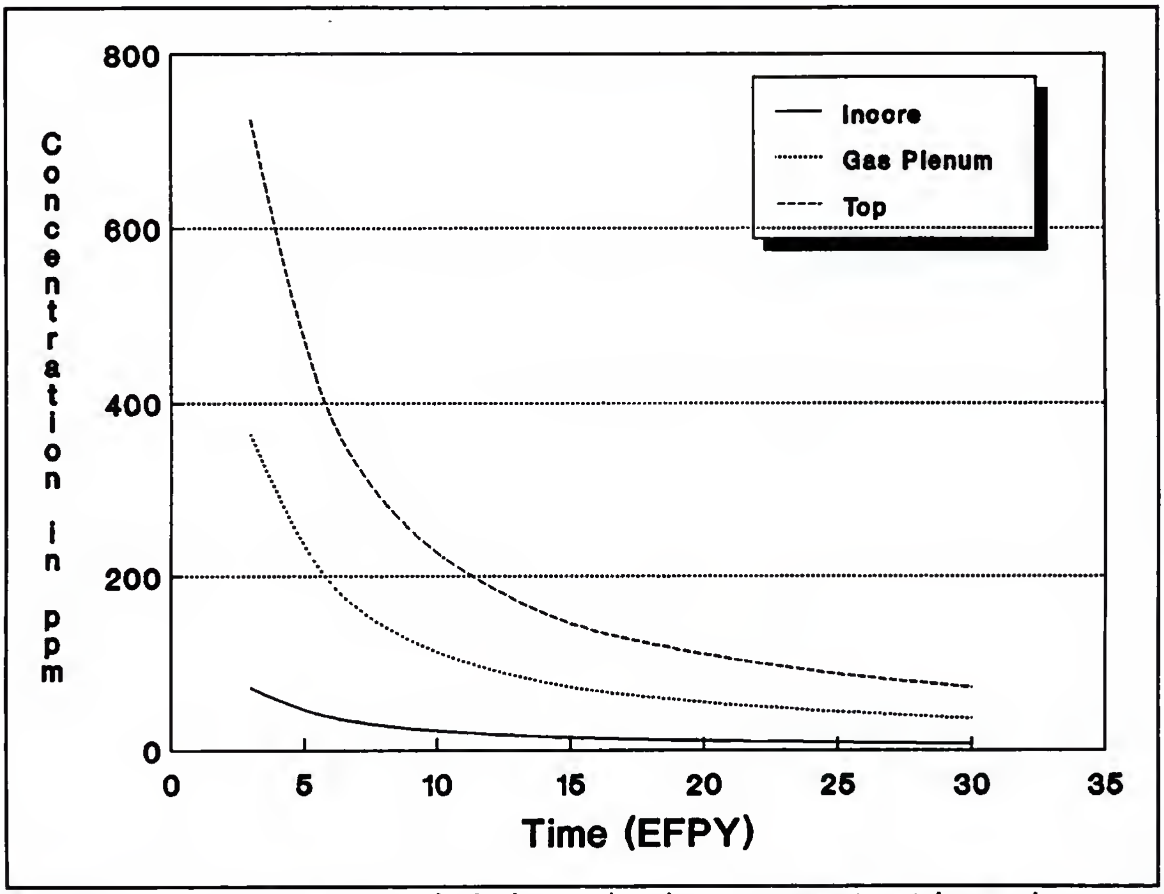

Figure 11. Allowable initial niobium concentrations in stainless steel as a function of irradiation time for three different vertical positions in the core.

In stainless steels, nickel represents a greater concern than does niobium. The allowable nickel concentrations shown in Figure 12 are again similar to the concentrations allowed in inconel. The average concentration of nickel in the stainless steel samples measured at PNL was about 9%, which is higher than the largest allowable concentration shown in Figure 12. However, these allowable concentrations also vary with vertical location in the core, so these values are not conclusive. The PNL study took twelve samples from

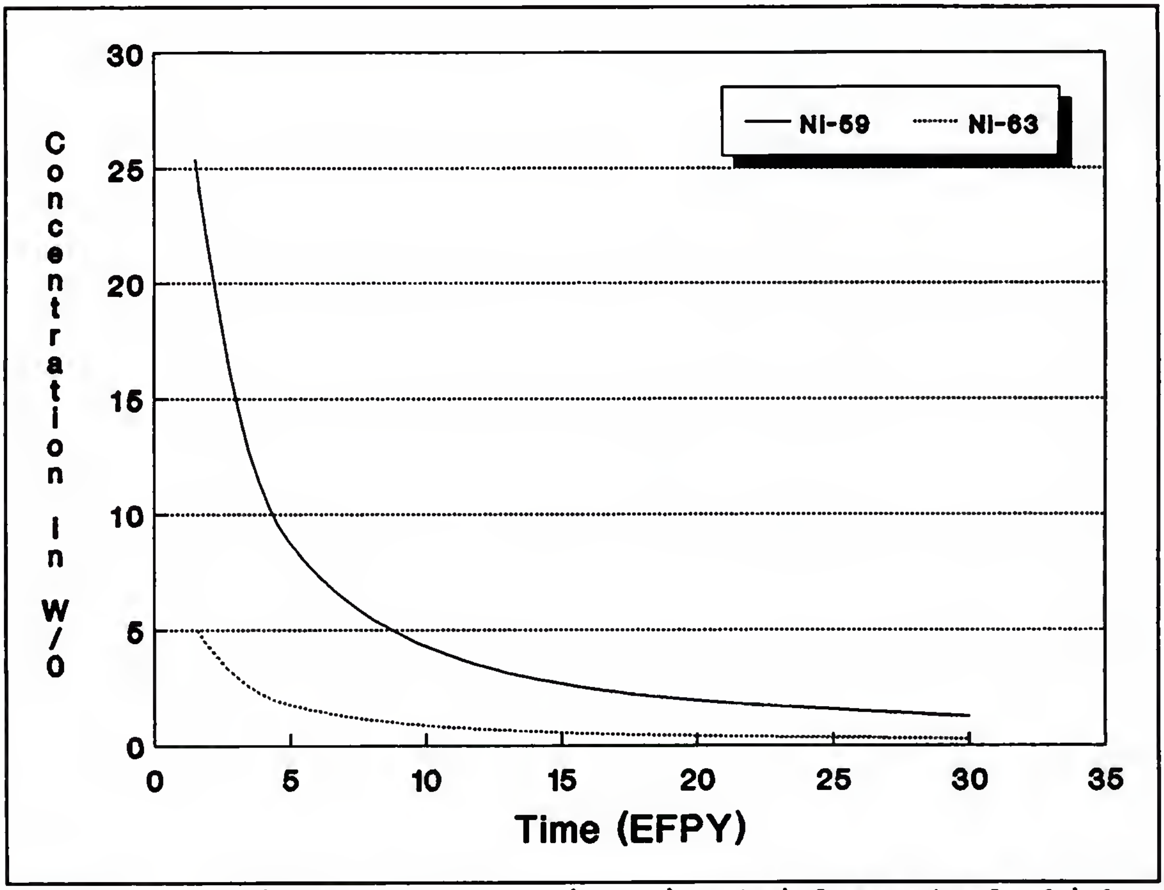

Figure 12. Nickel concentrations in stainless steel which will cause Ni-59 and Ni-63 to exceed their respective Class C limits as a function of time. (Φ=1x10^{13} neutrons/cm^2-sec.)

stainless steel endfittings, analysis of which revealed that ten samples classified as GTCC waste. The endfittings were irradiated in the top and bottom zones of the reactor for an average burnup of 34,000 MWD/MTU. These values will be used as a standard to evaluate individual NFA hardware types and to determine their classification.

Stainless steel is the most common NFA hardware construction material and is used for BWR control blades, the Palisades control blades, Babcock & Wilcox and Westinghouse PWR control rods, thimble plugs, neutron sources, some incore instrumentation, and some burnable poison rods. The PWR neutron sources (both primary and secondary), incore instrumentation, and burnable poisons are all irradiated in the core, so they experience a higher flux than components in the top region. The lifetime of the incore instrumentation is about five years, so it is commonly replaced after three fuel cycles. Since endfittings irradiated for this length of time classify as GTCC waste, so will incore instrumentation. Similarly, secondary neutron sources have a nominal lifetime of about 10 years (7 EFPY), so these components will also be GTCC waste. Primary neutron sources are used only for the first fuel cycle and then discharged. Similarly, the lifetime of burnable poison rods is only one cycle. Thus, these components are exposed for only one-third the duration of the endfittings, but by being incore, they are exposed to a ten times higher flux. Accordingly, these components will also classify as GTCC waste.

Concentration averaging will not change these classifications. For example, the 12 samples measured by PNL exhibited an average classification 5.42 times the Class C limit. Burnable poison rods are only irradiated for 1/3 the time, but at 10 times the flux, so the expected classification of the stainless steel is about 18 times the Class C limit. Since the stainless steel in the core region only represents about 50% of the total component volume, if the remainder of the component made no contribution to the measurement, the classification averaged over the entire component volume would still be approximately 9 times the Class C limit. In neutron sources, the incore stainless steel represents a larger fraction of the total component, while in incore instrumentation the stainless steel only represents about 25% of the total volume, but the component is irradiated for three times as long. Concentration averaging thus makes no difference in these cases.

Thimble plugs are irradiated in the gas plenum and top regions of the core. The lifetime of these components is highly variable, because thimble plugs are only replaced when they break. Accordingly, their lifetime can be quite long and is typically longer than three fuel cycles. However, many reactors have discontinued the use of thimble plugs, so some plugs may have been used for less than three cycles. Nevertheless, the majority of thimble plugs will have been irradiated for a longer period of time, and comparison with the endfitting classification indicates that

even those plugs irradiated for less than three cycles will probably classify as GTCC waste. Thimble plugs are constructed primarily of stainless steel and, due to their overall small size, all of the component is irradiated to roughly the same activation levels, so concentration averaging cannot reduce this classification. As a result, all thimble plugs will be classified as GTCC waste.

Both Babcock & Wilcox and Westinghouse control rods use stainless steel cladding. As the design lifetime of the control rods is about 16 years (10 fuel cycles or about 11 EFPY), these components would be expected to classify as GTCC waste. However, due to the manner in which PWR control rods are used, this may not be the case. As discussed earlier in conjunction with the Combustion Engineering control rods, PWR control rods spend a majority of their operational lifetime almost completely withdrawn from the core. The bottom tips of the control rods remain in the gas plenum region during operation and the rods are only fully inserted to shutdown the reactor. Since the flux is assumed to be zero outside the core, i.e. above the top zone, and at shut down, the majority of the control rod assembly is modelled to receive no irradiation and can be used to lessen the overall concentrations through concentration averaging.

The average stainless steel classification measured in the top zone by PNL was 1.57 times the Class C limit, while the average in the bottom zone was 9.3 times the Class C limit. Since the gas plenum zone and the bottom zone are

assumed to experience the same flux, the bottom zone measurement is used to model the gas plenum zone. Table 14 shows the metal volume of the stainless steel in the control rods relative to the overall control rod assembly, as well as the relative fractions of the stainless steel which are actually in the gas plenum and top zones. These fractions are based on a 160" control rod assembly, with 148" long control rods and zone sizes as described in Figure 5. Based on the relative volumes and acknowledging that the control rods are irradiated for 10 cycles, instead of 3 cycles like the endfittings, produces a net classification of 0.64 times the Class C limit. Accordingly, under normal operations, Babcock & Wilcox and Westinghouse control rods will classify as Class C waste and can otherwise be treated as LLW.

Table 14. The relative volumes of the materials in a Westinghouse Control Rod Assembly and the calculation of the component's waste classification.

Material	Weight	Density	Volume	Material Fraction
SS 304 (spider)	3.27 kg	8.02 g/cc	408 cc	6.6%
SS 304 (rods)	11.67 kg	8.02 g/cc	1455 cc	23.4%
Ag-In-Cd	43.12 kg	9.90 g/cc	4356 cc	70.0%

Total Control Rod Length: 148 inches

Fractional Volumes of Irradiated Materials:
Top Zone : 6/148 = 0.041 x 0.234 = 0.0096 = 0.96%
Plenum Zone: 12/148 = 0.081 x 0.234 = 0.0190 = 1.90%

Concentration Averaged Waste Classification
(Based on 3 cycles' irradiation):
Top Zone : 0.0096 x 1.57 = 0.015
Plenum Zone: 0.0190 x 9.30 = 0.177
0.192

Averaged Waste Classification at Design Lifetime:
0.192 x 10/3 = 0.64 -- LLW Waste

The situation experienced by the Palisades control blades is sufficiently different to require a separate analysis. The greater proportion of stainless steel in these control blades yields a higher 3-cycle classification than was the case for the control rods as shown in Table 15. And yet, the control blades would still qualify for LLW disposal after 10 cycles of irradiation. However, after the control blades' design lifetime of 20 cycles, the control blades will classify as GTCC waste. Accordingly, any Palisades control blades discharged after completing only 10 or fewer cycles will classify as LLW. However, those control blades exceeding 10 cycles should be considered GTCC waste. Fortunately, these control blades are only used at

Table 15. The relative volumes of the materials in a Palisades Control Blade and the calculation of the component's waste classification.

Material	Weight	Density	Volume	Material Fraction
SS 304	28.20 kg	8.02 g/cc	3516 cc	34.0%
Ag-In-Cd	68.86 kg	9.90 g/cc	6956 cc	66.0%

Total Control Blade Length: 151 inches

Fractional Volumes of Irradiated Materials:
Top Zone : 6/151 = 0.040 x 0.34 = 0.013 = 1.3%
Plenum Zone: 12/151 = 0.080 x 0.34 = 0.027 = 2.7%

Concentration Averaged Waste Classification
(Based on 3 cycles' irradiation):
Top Zone : 0.013 x 1.57 = 0.021
Plenum Zone: 0.027 x 9.30 = $\underline{0.251}$
0.272

Averaged Waste Classification at Design Lifetime:
0.272 x 20/3 = 1.674 -- GTCC Waste

one reactor, so they do not represent a major disposal concern in any case.

On the other hand, there will be a large volume of BWR control blades requiring disposal. For BWR control blades, the relative material volumes are most closely approximated by the Palisades control blades. Thus, like the Palisades control blades, the stainless steel represents a greater percentage of the total hardware volume than was the case in the PWR control rods. In addition, these control blades are inserted from the bottom of the reactor, and it has already been noted that the flux and activation levels in the bottom zone are higher than those in the top zone. Finally, BWRs typically operate with banks of control blades partially inserted into the core for axial power shaping. As a result, both a higher percentage of the overall components is irradiated than was the case for PWR control assemblies, and the irradiation occurs in the incore zone which has a significantly higher flux. These factors will result in the BWR control blades classifying as GTCC waste.

Zircaloy is the final material to be examined. The nickel isotopes do not make a significant contribution to the waste classification of zircaloy components because nickel is only present as an impurity. The maximum nickel concentration measured in a zircaloy sample by PNL (0.08%) is more than a factor of 10 below the allowable nickel concentration after 30 years of exposure as shown in Figure 13. Since the most significant use of zircaloy in

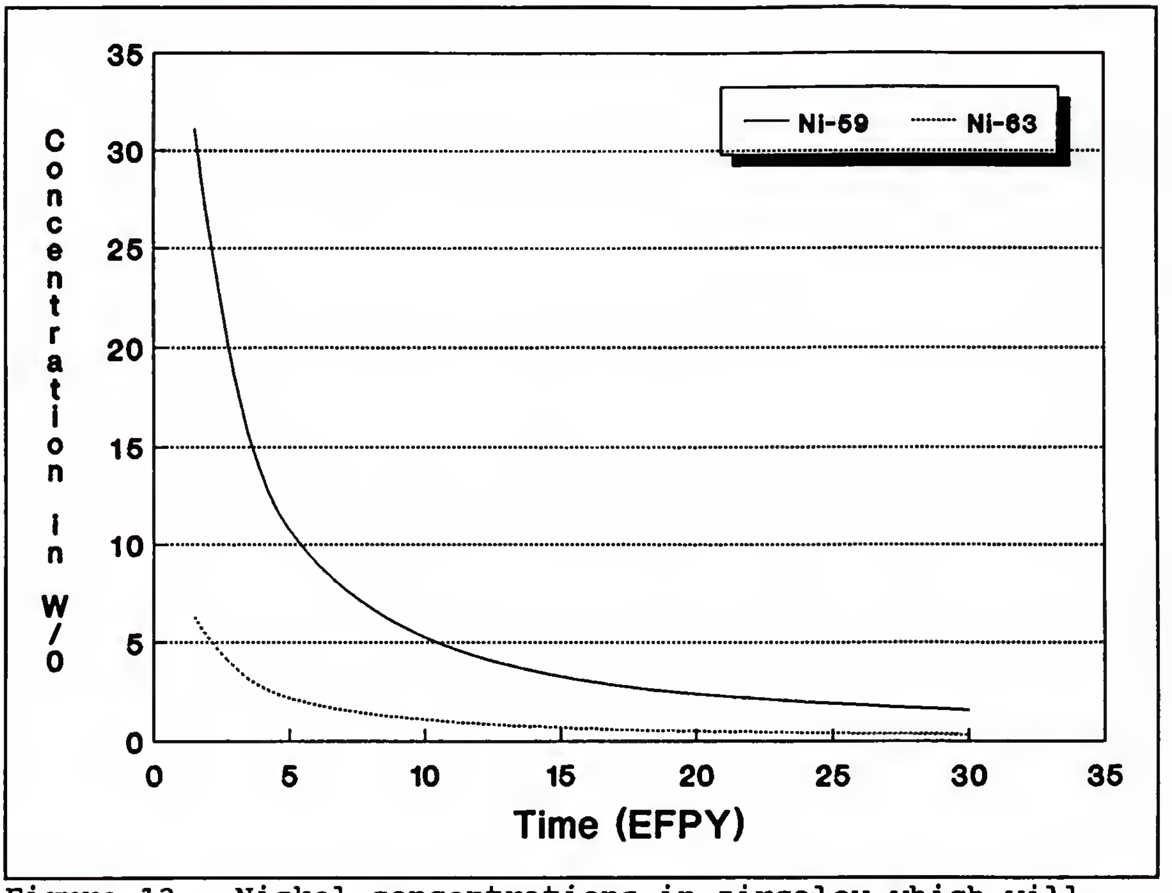

Figure 13. Nickel concentrations in zircaloy which will cause Ni-59 and Ni-63 to exceed their respective Class C limits as a function of time. ($\Phi=1x10^{13}$ neutrons/cm^2-sec.)

NFA hardware is in BWR fuel channels which are irradiated for not more than 6 reactor cycles (approximately 9 years), the actual nickel concentrations are well below the acceptable limit.

Niobium, on the other hand, represents a concern even in zircaloy components. Because niobium is also considered an impurity, the material specifications for zircaloy exclude any mention of niobium, but the actual niobium concentrations found by the PNL analysis ranged "from below detectable limits to several hundred ppm."[48] Comparison

with the allowable concentrations shown in Figure 14 indicates that samples with niobium levels of several hundred ppm could exceed the Class C limits. Based specifically on the use of zircaloy in BWR Fuel Channels, the typical lifetime of which is one assembly lifetime, or about 4.5 years, the maximum permissible niobium concentration is about 140 ppm. If the channel is re-used for another assembly lifetime, the total time of exposure is about 9 years of operation, or 6 EFPY, and the permissible concentration drops to roughly 70.0 ppm.

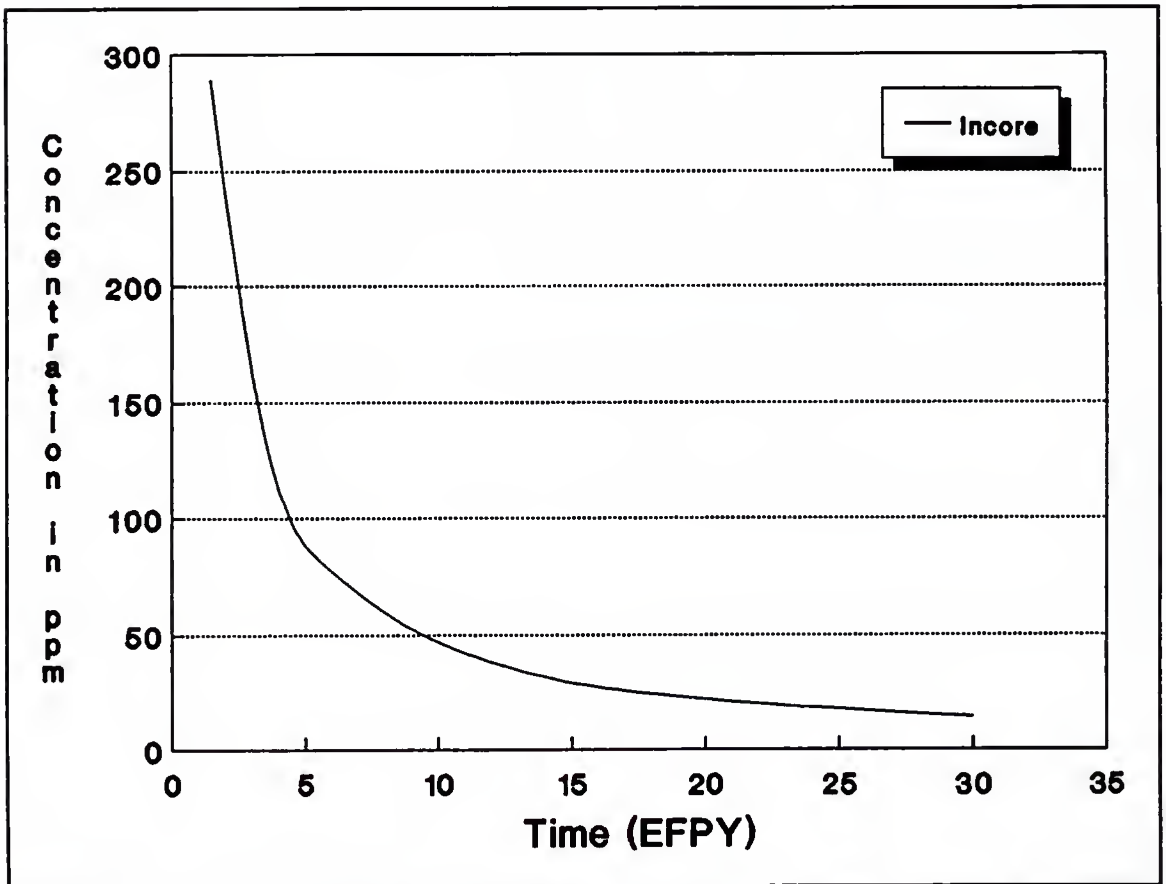

Figure 14. Niobium concentrations in inconel which will cause Nb-94 to exceed its Class C limit as a function of time. (Φ=1x10^{13} neutrons/cm^2-sec.)

The results of previous analyses have been contradictory. Based in the ORIGEN2 runs performed for the CDB, ORNL indicated that all zircaloy hardware classified as GTCC waste. A niobium concentration of 120 ppm was assumed for these calculations.[44] The work at PNL found the zircaloy hardware classifications to be inconclusive. While none of the measured values actually exceeded the Class C limits, some of the values were close enough to the limit for statistical uncertainties to be significant to the waste classification. Furthermore, due to the complex and expensive procedures required to measure the niobium concentrations, not all zircaloy samples were analyzed for niobium, thus increasing the degree of uncertainty in the measured values. Of note, however, is that in the 6 samples analyzed for niobium (out of a total of 15 zircaloy samples), an average concentration of 127 ppm was measured. Finally, RG&E concluded that all zircaloy components could be disposed of as LLW.[7] However, it is uncertain if the presence of niobium was measured or otherwise accounted for by the RG&E work.

Resolution of these varying evaluations into a single general approach to classification is difficult. The conservative approach would be to classify all zircaloy components as GTCC, in which case, other than some PWR control rod assemblies, all NFA hardware would be treated as GTCC waste. This approach is supported by the practices of foreign countries like France and the United Kingdom.

However, both the PNL and RG&E results indicate that this may not be necessary. The PNL sample which was closest to the Class C limit (97% of the limit)[49] was taken from a grid spacer near the middle of the assembly, contained a niobium concentration of roughly 200 ppm,[50] and had been subjected to a burnup of 41,800 MWD/MTU.[51] Two other samples exposed to this burnup, but taken from other grid spacers on the assembly which only contained niobium concentrations of about 120 ppm, exceeded 50% of the Class C limits (achieving 55% and 68% of the limit). All three samples achieved these levels based solely on the ^{94}Nb activation levels. Since the two samples achieved an average classification of 0.62 at 41,800 MWD/MTU, it can be estimated that the samples would have reached the Class C limit after experiencing a burnup of roughly 67,400 MWD/MTU. Taking into account that this is an approximation and that a higher burnup would be required before the samples actually exceed the Class C limit, the burnup limit will be rounded up to 70,000 MWD/MTU. Accordingly, zircaloy components which experience a burnup of less than 70,000 MWD/MTU should be suitable for shallow land burial and may otherwise be treated as LLW. However, components which experience a burnup of 70,000 MWD/MTU or greater should be classified and treated as GTCC waste. The only NFA hardware which currently uses zircaloy is BWR fuel channels and some Babcock & Wilcox and Westinghouse burnable poisons. Due to the high burnup cutoff proposed here, only BWR fuel channels

which are used for two or more fuel assembly lifetimes, and which experience above average burnups, will be considered GTCC waste. In practice, however, since the majority of BWR fuel channels will only be used for one fuel assembly lifetime, any channel which does exceed the Class C limit can be averaged with other channels which have not exceeded the limit to reduce the classification. Accordingly, all zircaloy components are expected to classify as LLW.

The general waste classifications for NFA and SFD hardware produced as a result of this work are summarized in Table 16. In general, only hardware constructed of zircaloy and subjected to a burnup of less than 70,000 MWD/MT and PWR control rods constructed of stainless steel are considered LLW. Additionally, Palisades control blades which are not used for more than half of their design lifetime may also be considered LLW. It should be noted that the classifications given for the PWR control rods and the Palisades control blades do not contradict the classifications given in Table 16, because these hardware elements generally do not

Table 16. A summary of the final waste classifications for NFA and SFD hardware based on material of construction and burnup. These classifications assume a minimum irradiation time of one EFPY within the reactor core.

Material	Burnup (MWD/MTU)	Classification
Inconel	All	GTCC
Stainless Steel	> 2,000	GTCC
Zircaloy	< 70,000 >= 70,000	LLW GTCC

achieve the minimum irradiation time of one EFPY in the reactor core. The waste classifications by hardware type and material of construction are summarized in the "Waste Classification" section of Chapter 5.

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CHAPTER 3
FOREIGN HARDWARE WASTE HANDLING

While nuclear energy is a global resource, radioactive waste management is also a global concern. Every nation which has ever operated a nuclear power plant must make some plans for the disposal of the waste generated by such plants. And to a lesser extent, with the widespread usage of nuclear medicine and other applications of radioisotopes, all developed countries will generate a small amount of radioactive waste which must be disposed of safely. Careful examination of the progress made by other countries presents a strong potential source of information upon which the waste management programs in the United States may draw, a source which should prove highly beneficial.

In order to make use of the results of foreign research, the terms and classifications used abroad must be understood in relationship to those used in the United States. The most notable difference in waste classifications is that in place of the LLW and HLW classifications used in the United States, most other countries have three classifications, namely LLW, Intermediate-Level Waste (ILW), and HLW. Aside from some minor differences in actual radioisotope limits and differing methods of measuring these limits, definitions of foreign LLW and domestic LLW are similar. HLW classifica-

tions are also fairly uniform throughout the world. The ILW classification, on the other hand, generally includes such wastes as NFA hardware, filter sludges, and spent ion resins[1] and is most nearly equivalent to the American GTCC LLW classification. However, generally speaking, foreign ILW is better defined and more widely recognized than is GTCC LLW in the United States.

The methods for the safe disposal of radioactive wastes are many and diverse, and vary as a function of the waste classification and the country performing the disposal. The waste disposal policies being followed in the United States are examples of only one approach, but are in many ways quite similar to most foreign approaches. Additionally, with only a few exceptions, the time schedules for development of disposal facilities are also very similar throughout the world. LLW disposal is generally the most advanced while most HLW programs are expected to begin operations early in the 21st century. Nevertheless, the overseas methodologies do differ from that of the United States and thus offer alternate viewpoints and contrasting data on the waste management question in general. Examination of this data is necessary for the proper development of our own domestic waste management programs.

Hardware Waste Programs

The general progress and state of readiness of a country's waste management program is often a reflection of

the state of its nuclear industry. As such, the most advanced waste management programs are found in Europe and Japan. As practitioners of spent fuel reprocessing, the United Kingdom and France have both developed their waste management technology to handle the waste resulting from the operations of these plants. West Germany abandoned fuel reprocessing in 1989, but they have active waste management experiments being conducted in the Asse salt mines, a comparable environment to that for which a repository is eventually intended. Sweden also does not pursue reprocessing, but as a result of political pressures has developed active storage and disposal facilities ahead of any other country. Finally, Japan currently relies on France and Britain for reprocessing of its spent fuel, but is currently developing its own reprocessing capability as well as working towards developing a waste management strategy. All of these programs are sufficiently advanced to provide useful input for the American waste management programs.

France

In today's nuclear energy community, France clearly stands out as one of the world's leaders. In 1988, with roughly 100 operating commercial nuclear reactors, the United States had twice the number of reactors of France, where there were only 51 such reactors; the French reactors, however, represented a much greater percentage of the

country's total electricity generation. The French nuclear power facilities represented about 74% of the total electricity generated in France during 1988[2] while nuclear energy accounted for only slightly less than 20% of the total electricity generated in the United States during the same year, thus illustrating the total commitment to nuclear energy which France has made. Furthermore, in the February 1991 "World List of Nuclear Power Plants," a semi-annual listing published in Nuclear News by the American Nuclear Society, France was listed as having 53 operational nuclear plants and 8 plants under construction,[3] thus confirming their continuing commitment to this technology.

France is also one of a very few countries which have active spent nuclear fuel reprocessing facilities. Both the UK and the USSR are also currently operating reprocessing facilities, and Japan intends to begin an active reprocessing program in the near future, but of the 25 nations world-wide who utilize nuclear power reactors,[4] no others are currently pursuing such plans. The French currently have three operational reprocessing facilities, one at Marcoule and two at La Hague. At Marcoule, the UP1 plant has been in operation since before 1966 and is used to reprocess Gas Cooled Reactor fuels from the Electricité de France plants and the Franco-Spanish Vandellos plant. The two newer reprocessing facilities at La Hague, UP2 400 and UP3, are responsible for the reprocessing of LWR fuels. UP2 400 had reprocessed 2901 tons of LWR fuel from both foreign

and domestic reactors from startup in 1976 through the end of 1989. The UP2 800 project is currently under construction with the purpose of doubling the capacity of UP2 400. UP3 began partial operation in 1989[5] and full-scale commercial operation in September 1990.[6] The plant's construction was financed entirely by foreign customers who, in exchange, were given rights to the total output of the plant for the first ten years of operation.[7] Waste generated through the reprocessing of foreign fuels will be shipped back to the country of origin, but the domestic fuel waste must be dealt with internally, and it is this experience which is of potential use to other countries for their own waste management programs.

The French plants utilize the chop and leach technique for the reprocessing of LWR fuel elements. The end fittings, assembly hardware, and hulls generated by this procedure are disposed of "in line" immediately after the chopping stage. The end-fittings are immediately acid-rinsed and fed into a disposal container. The assembly hardware and fuel pins, on the other hand, are first sent through the dissolver to remove the fuel, then are acid-rinsed and gravity fed into the same disposal container as the end-fittings. Early indications were that the disposal container used for this hardware would be a concrete shell which, when filled, would have a cement grout introduced to properly immobilize the hardware after which the package would be sealed with a concrete lid. The resulting waste

form would have been a solid concrete block of 570 liters volume.[8] However, recent correspondence with Cogema indicates that stainless steel containers of unspecified size are now used. The remainder of the procedure is still the same, i.e. the waste is immobilized with a cement grout and the container is sealed with a double lid.[9] The quantity of hardware generated during reprocessing is approximately 0.5 m^3 per ton of fuel reprocessed.[8] These hardware waste drums are then stored in a pool[10] for an indefinite period until final disposal. After the interim storage period, these containers will be sent to a deep geologic repository.

United Kingdom

With 37 reactors[11] representing 20% of the total electricity generation[12] in 1990, the United Kingdom also makes extensive use of nuclear energy and is, together with France, a world leader in spent fuel reprocessing. The Sellafield reprocessing plant currently processes domestic Magnox fuels while the Thermal Oxide Reprocessing Plant or THORP, which is expected to begin commercial operation in 1993, will reprocess the Advanced Gas-cooled Reactor (AGR) fuels. Additionally, THORP has reprocessing contracts for spent fuel from the former West Germany and has also taken fuel from Japan into its storage pools to await reprocessing.[13] The SFD hardware generated in these facilities is handled in different ways depending on the

type of fuel reprocessed. The dominant fuel types in the UK are Magnox, AGR, and PWR fuels.

Magnox fuel is disassembled at the reactor site prior to shipment to Sellafield for reprocessing. The discarded fuel hardware materials include attachments to the magnesium alloy can such as flow splitter blades, Magnox lugs, and end pieces. In one station, the fuel design has graphite struts and at another, the design includes a graphite sleeve, all of which are removed prior to shipment.[14] The discarded hardware is stored on-site in either wet or dry storage vaults awaiting future processing.[15] In some cases, the material will be reacted with CO_2 and water to allow inactive magnesium bicarbonate to be discharged to sea.[16] Solid residues are then expected to be put into 500 liter drums and immobilized with a cement-based grout.

In the case of AGR fuel, fuel stringer debris such as tie-bars, central inertial collectors, and thermocouples are held on-site in void spaces inside the reactor shielding until Stage 3 decommissioning.[17] During Stage 3 decommissioning, all remaining radioactive parts are removed and the site is releases for unrestricted use.[18] At this time, the remaining hardware is disposed of as part of the decommissioning wastes. The actual fuel elements are disassembled upon receipt at Sellafield in remotely operated caves built for this purpose.[19] The hardware removed at this time includes graphite sheaths and stainless steel grids. The actual fuel elements are then returned to the

fuel storage ponds to await reprocessing at THORP, while the hardware waste is stored dry in 500 liter drums pending final processing at a later date. Again, processing methods have not been finalized, but the hardware is expected to be sent to a separate encapsulation facility for processing where it will most likely be transferred to other containers and cemented in place.

PWR fuel in the United Kingdom will be reprocessed at THORP when it begins operation in 1993, and will be mostly from foreign sources as the United Kingdom currently has plans for only one PWR plant, Sizewell B, which is not expected to begin operation until 1995. This fuel will not be disassembled prior to reprocessing. Instead, the entire assembly (end fitting, fuel pins, spacers, etc.) will be chopped into 1" pieces and fed into a dissolver. After the fuel is leached out, the hardware and hulls will be sent to an encapsulation plant where they will be metered into 500 liter drums and cemented in place. The wastes resulting from foreign fuel will be returned to the country of origin with the reprocessed fuel.

Most NFA hardware generated at the various plants throughout the country are treated by similar means. The hardware is expected to be held on the reactor site until Stage 3 decommissioning[17] at which time it will be treated, conditioned, and disposed of in the same manner as the other decommissioning waste. The waste will then be cut to fit into 500 liter drums, 3 m^3 boxes or 12 m^3 boxes, as

appropriate for the particular hardware items in question,[20] immobilized by cementation and then disposed of at a deep geological repository.

All of the hardware items discussed above are classified as ILW[21] and are treated by the same methods. Immobilization in cement was chosen for use in the United Kingdom because the cement

> met the widest range of essential and desirable criteria, such as: a monolithic product, suitable for at least 50 years' storage; activity retention characteristics (as a result of chemical properties, i.e. high pH and sorption capacity); adaptability, to suit the individual waste properties; [and a] low temperature, simple process.[22]

This cementation will most likely take place at the new encapsulation plant in Dounreay.[23] In all cases, the resulting waste forms are to be stored until the opening of a deep geologic repository for their disposal. UK Nirex Ltd., the British radioactive waste management organization, is currently characterizing two potential sites for such a LLW and ILW repository, one near Dounreay and one near Sellafield. Current estimates call for this repository to be operational around the year 2005.[24]

One deviation from the NFA hardware policy was noted. Waste hardware from the one experimental Liquid Metal Fast Breeder Reactor (LMFBR) facility at Dounreay was found to suffer from sodium contamination which complicated the disposal process. Most of these hardware items could be cleaned and would then be treated like the hardware from other facilities (i.e. cut and fit into 500 liter drums,

then cemented), but the control elements cannot be cleaned by the standard methods and an alternative has yet to be found, so the method of their disposal is currently unresolved.[25]

West Germany

Nuclear energy in the former West Germany was provided by 21 reactors[26] and represented 39.5% of the nation's total electricity generation in 1989.[27] The recently reunited Germany now boasts a total of 28 nuclear plants, but due to safety concerns centering around the East German reactors, only 21 of these are currently in operation.[3] It is unclear whether the other 7 are permanently shutdown, or if they are only temporarily shutdown for extensive backfitting. Nevertheless, nuclear energy will undoubtably continue to provide a significant portion of the electricity generation in the united Germany.

Spent fuel reprocessing in West Germany began on a pilot-project scale in 1971 at the Karlsruhe reprocessing facility (WAK). The plans to develop a full-scale reprocessing plant at Wackersdorf (WAW) met with numerous delays which ultimately resulted in the plant's abandonment in 1989.[28,29] Nevertheless, the WAK operations generated SFD hardware waste which, according to the West German waste classification methodology, classifies as ILW. The waste was processed in the plant as it was generated by mechanical reduction and cementation into steel drums. These drums

were then transported in heavily shielded casks to a hot-cell storage facility at the Nuclear Research Center Karlsruhe (KfK) waste treatment works where they will be stored until permanent disposal is available.[30]

In addition to the pilot project wastes, Germany will have more reprocessing wastes to dispose of. By German law, all nuclear utilities are responsible for ensuring that the Entsortung, or back-end of the fuel cycle, is adequately accounted for. Accordingly, since the abandonment of the domestic WAW reprocessing facility, several West German utilities have made arrangements to have their spent fuel reprocessed by British Nuclear Fuels plc (BNFL). The fuel will be reprocessed on or after the year 2003 at the new THORP plant which is currently under construction. Germany is now the second largest foreign customer of BNFL, second only to Japan. Other German utilities have made similar arrangements with the French company Cogema. In either case, the wastes from the reprocessing will be treated by the reprocessing company in accordance with each country's standard practices, but will then be returned to Germany for actual disposal.[31]

Also part of the ILW category is NFA hardware which is generated as operational waste at the German nuclear plants. Treatment consists of underwater cutting and packaging of the hardware into heavily shielded casks. The casks are then sealed and the contents are dried using valves built

into the cask for that purpose. The hardware is not cemented or otherwise immobilized.[32]

The methods of disposal intended for ILW in Germany depend on whether the waste is heat-generating or non-heat-generating. As the hardware discussed here is heat-generating waste, the planned disposal technique is referred to as the ILW Borehole Technique. The waste is first placed into 120 liter removable inserts which are in turn placed within standard 200 liter drums. The hardware is then immobilized using Portland cement PZ 45F with a water/cement ratio of 0.45 and approximately 1% of concrete thinner. These waste packages are sealed with a double lid arrangement and will then be placed in 300m deep vertical, unlined boreholes in a salt repository.[33]

The Asse salt mine was used from 1967 to 1978 for the disposal of LLW and small quantities of ILW. Since then, the mine has been used for in-situ testing of heat-generating Intermediate-Level Waste packages to benchmark the ILW Borehole Technique for use elsewhere.[34] At this time, the most likely location for heat-generating ILW disposal in Germany is the Gorleben salt dome. If found suitable and subsequently licensed, Gorleben has an estimated 83,000 cubic meters of borehole volume available for heat-generating Intermediate-Level Wastes.[35]

Japan

Japan is another country which generates a significant portion of its electricity through the use of nuclear energy. With 40 reactors[11] producing 27% of their electricity[12] in 1990, Japan's nuclear power industry surpasses all other Oriental nations and many European ones. Japan is also one of the few nations in the world pursuing spent fuel reprocessing. In 1977, the Japanese began small-scale spent fuel reprocessing operations at the Tokai Reprocessing Plant in Tokai-mura. In 1989, the Tokai plant reprocessed roughly 10% of Japan's spent fuel, with the remainder being processed overseas.[36] The Tokai plant utilizes the chop and leach method and the resulting chopped SFD hardware is classified as High-Level Solid Waste or HLSW. The HLSW is placed into special containers for transport to HLSW storage where the hardware is stored in pools pending final disposal.[37] A Hot Isostatic Pressing process for volume reduction is being developed.[38]

Decommissioning wastes, particularly the contaminated metal wastes which include the reactor internals and some NFA hardware, are cut and stored in large canisters pending final disposal.[39] At the current time, the Japanese have decided not to grout the hardware. The hardware is stored loose within the canisters, but some means of immobilizing the waste may be designated before the waste's final disposal. Additionally, melting the hardware waste before

disposal is also being studied as a volume reduction technique.[39]

Several volume reduction methods are in use at the Pu-Contaminated Waste Treatment Facility (PWTF), also located in Tokai, which could be readily adapted to handle reactor hardware waste. Pu-contaminated metal wastes, in particular, are melted into ingots by electro slag remelting. The ingots are then placed within specially designed canisters to await final disposal.[40,41] This technique has not yet been applied to NFA and SFD hardware, but demonstration of the technique at the PWTF is proceeding on similar materials, so such an application may be forthcoming.

Final disposal plans for NFA and SFD hardware have not been developed. Prior experience has shown that the Japanese tend to begin with the general techniques set forth by the United States and then to modify those plans to suit their own particular situation. Accordingly, Japan is working towards the development of a deep geological repository for the ultimate disposal of its HLW, but at this time no plans for the disposal of hardware wastes have been made.

Sweden

The nuclear power program in Sweden is one of the more advanced programs in the world, but ironically is also one of the most threatened. Between 1972 and 1985, Sweden built

12 nuclear power stations which now produce roughly half of Sweden's total electricity supply.[42] However, the results of referendum conducted in 1980 caused the Swedish parliament to develop a plan whereby all of Sweden's nuclear power stations would be phased out by 2010 and decommissioned thereafter. The plan did stipulate, however, that acceptable methods of replacing the power generated by these plants had to be found before the plants could be shut down. As Sweden has already tapped all of its economical hydroelectric potential and fossil fuels are considered unacceptable due to acid rain concerns, the search for suitable replacements has not been successful. In addition, recent polls have indicated that public opinion in Sweden is changing in favor of nuclear power[43] which, in combination with the lack of alternatives and recent favorable changes within the Swedish government,[44] provides some hope for the future of nuclear power in Sweden.

If spite of, or potentially because of, the planned phase out of nuclear energy, Sweden has developed the most advanced radioactive waste management program in the world. By Swedish law, the individual utilities are responsible for the management and disposal of all radioactive wastes which they generate. To meet this requirement, the four nuclear utilities in Sweden formed a jointly-owned corporation known as the Swedish Nuclear Fuel and Waste Management Company or SKB. This company has been charged with the planning, building, ownership, and operation of all the equipment and

facilities necessary for the safe disposal of the utility's radioactive waste. The company's operation is, in turn, supervised by an agency of the Swedish government.[42,45]

SKB's waste management plan calls for the construction and operation of three facilities. The Swedish Final Repository or SFR is for the disposal of Intermediate- and Low-Level Wastes, the Central Interim Storage Facility for Spent Nuclear Fuel (CLAB) handles the temporary storage of spent nuclear fuel, and the Swedish Final Repository for Spent Nuclear Fuel (SFL) will be for the final disposal of the spent fuel. Of these facilities, the SFR and CLAB facilities are already operational. The SFL is expected to begin operation around the year 2020.[42]

The SFR was built off the Swedish coast near Forsmark and is situated approximately 60m below the seabed of the Baltic Sea. This facility is designed to handle all of the ILW and LLW generated by the nation's nuclear plants as well as any that is generated by the other SKB facilities like the CLAB. The LLWs are emplaced into drifts while the ILW is placed in concrete-lined vertical silos. In both cases, the waste is covered with cement after a section is filled and then the adjacent tunnel area is back-filled with rock and bentonite clay. A future expansion to the facility is planned to accommodate decommissioning wastes.[42,46]

The second operational facility is the CLAB which was constructed at Oskarshamn, also on Sweden's east coast.

> The actual storage building is located underground in a rock cavern whose ceiling is located 25-30

> meters below ground level. The rock cavern is lined with shotcrete and reinforced with rock bolts. Inside the ceiling is a lining of sheet metal.[47]

The current storage capacity of the facility is approximately 3000 tonnes of spent fuel, but an expansion is planned for the mid-1990's which will increase the storage capacity to roughly 7800 tonnes, large enough to hold all of the spent fuel from the Swedish nuclear power program.[48] CLAB will hold its wastes for 40 years, after which time it will be encased in sealed copper canisters and deposited in the SFL.[42] The site of the SFL has not yet been selected, but since the SFL is not expected to begin operations until the year 2020, there is time to select one.

The nuclear industry in Sweden should not generate any SFD hardware for two reasons. First, the Swedish government desired their fuel cycle to be completely independent of all foreign countries, so they conduct no fuel reprocessing. Instead, Swedish utilities which had pre-existing reprocessing contracts with Cogema made arrangements with German utilities to accept some German spent fuel assemblies for disposal, in exchange for which the German utilities assumed the Swedish reprocessing contracts.[49] And secondly, with the CLAB facility already operational, there is no shortage of storage space for spent fuel, therefore there is no need to pursue fuel consolidation as is being examined here in the United States. Current Swedish plans call for the fuel assemblies to be disposed of intact and with them will go all SFD hardware.

NFA hardware, on the other hand, is generated as operational waste and these core components will be shipped to the CLAB pending shipment to the SFL after the appropriate waiting time.[50] This reactor hardware is packaged into shipping casks which are similar to those used for spent fuel, but lack cooling fins and neutron radiation shielding.[51] The filled casks are shipped to the CLAB by sea where they are transferred to the storage pools. Like the spent fuel assemblies, the hardware will be stored for 40 years before being encapsulated in sealed copper canisters and transferred to the SFL for final disposal.

Hardware Handling Summary

Of the five countries examined, four are actively involved in the generation and subsequent disposal of SFD hardware. In the United Kingdom, Germany, and France, the SFD hardware is classified as ILW. In all three countries, the SFD hardware is metered into drums of various sizes and immobilized with a cement-based grout. In Britain and France, the hardware generated by the reprocessing of domestic fuel is stored pending final disposal in a deep geological repository which will be built specifically for Intermediate-Level Wastes. All wastes from the reprocessing of foreign fuels are returned to the country of origin. Germany is no longer developing their own reprocessing capability and has instead contracted with the United Kingdom and France for these services. The German SFD

hardware waste generated by the reprocessing pilot project together with the waste which will be returned from Britain and France is intended for disposal in a future salt-dome repository, possibly at Gorleben. Tests of this disposal method are currently under way in the Asse salt mine. In contrast to the German abandonment of reprocessing, Japan is currently seeking to develop their own reprocessing technology. The SFD waste generated at the Tokai reprocessing plant is referred to as High-Level Solid Waste and is currently stored in pools pending future processing. Such processing is projected to include loose packing in drums (i.e. no grouting) following by Hot Isostatic Pressing for volume reduction. The waste packages will then be stored until a repository is developed.

NFA hardware and core components require different initial treatment than SFD hardware, but the final disposal plans are proceeding along similar lines. Sweden treats the material as if it were spent fuel and is storing it at the CLAB facility until the spent fuel repository is opened. Germany and Japan both cut their NFA hardware to fit into casks and then store the casks until disposal. They do not grout their NFA hardware. Most NFA hardware in the United Kingdom will be stored at the reactor site until Stage 3 decommissioning at which time it will most likely be cut, packed into drums, and cemented. However, the control rods from the experimental LMFBR can not be treated in this way and currently represent an unresolved problem. The author

was unable to obtain any information on the practices of France with regard to NFA hardware.

Several observations can be made based on these analyses. First, all of the countries studied classify SFD hardware (which in these cases also contain the fuel element cladding in the form of hulls) as either ILW or HLW. Second, the SFD hardware is intended to be packaged in drums, with or without concrete grouting, and disposed of in a deep geologic repository. Third, the countries which have established practices for the disposal of NFA hardware will be storing the hardware for an indefinite period, cutting and packaging the hardware in drums, storing the conditioned waste packages for another indefinite period, and then disposing of the packages in a deep geologic repository. The most important note is that none of the countries studied treat any of these hardware wastes as LLW.

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CHAPTER 4
HARDWARE WASTE EXPERT SYSTEM

In planning for the development and eventual operation of the Federal HLW Repository, it is essential to have accurate information on the quantities and characteristics of the wastes which are expected to be disposed of therein. The majority of waste to be emplaced in the repository will be spent fuel and HLW from commercial power plants and defense activities, respectively. Additionally, as described in Chapter 2, the DOE is also obligated to accept for disposal all NFA and SFD hardware. This hardware is currently expected to go to the repository, so that its quantities and characteristics are also needed by OCRWM. The current state of knowledge about the characteristics of this hardware and the status of the studies on it were discussed in Chapter 2. The HWES has been developed for the purpose of improving the accuracy of this data.

The Expert System approach was chosen for a number of reasons. First, a computer program was desired due to the large number of calculations to be performed. Calculating the expected number of hardware components discharged by any particular reactor is not difficult to perform by hand. However, performing the same calculations for 126 reactors over a variety of time spans would be tedious and time-consuming. Furthermore, a program could also calculate the

weight, volume, and waste classification of this hardware in the time needed to perform one quantity calculation by hand. Therefore, developing a computer program to perform these calculations was deemed more efficient.

Second, as the CDB represents the primary data source for the calculations, the program would need an advanced dBase interface to extract this data. For data not contained within the CDB, the program should be capable of explaining the data requests that are made. Specifically, as the user may only have general knowledge about the hardware being studied, both an explanation of why the data is needed and a clarification of the nature of the required data would be useful to the user. It would also be beneficial for the program to be able to explain how the results were obtained to provide self-documentation. All of these features could be provided by an Expert System.

Another desirable characteristic of Expert Systems is the ease with which an Expert System can be expanded and maintained. Expert Systems are designed to be maintained by the user; extensive programming or editing skills are not required. As a result, the Expert System can be readily adapted as new methods are developed and expanded as new types of estimates become desirable. Additionally, the majority of information required by this particular Expert System application is extracted from the CDB. The CDB files are maintained with dBase III+, so by using an Expert System which can draw on these files directly, the ease of

maintaining the knowledge within the system is further increased. In many cases, the Expert System itself will not need to be altered in order to keep the knowledge current. Thus, an Expert System is likely to maintain its usefulness over time which provides further incentive to develop the Expert System.

Expert Systems

Expert Systems are the result of ongoing research into Artificial Intelligence (AI). "Early AI development looked for simple and powerful reasoning techniques that could be applied to many different problems."[1] The goal was to develop a problem solving machine that could solve a wide range of problems using general techniques. One such Expert System precursor was the General Problem Solver or GPS.[2] However, while these general methods proved adequate for general problems, they rapidly broke down when applied to specific, real-world problems which required large quantities of detailed knowledge.

As research on problem solving continued, the domain upon which these machines were expected to work narrowed in scope. Instead of the general problems that were originally tried, the machine (computer) was given more and more specific information on an increasingly narrow field until the concept of the "Expert System" was developed. Expert Systems rely on detailed expert knowledge in very narrow fields of application to make their decisions. One early

example of an Expert System is MYCIN.[3] Development of MYCIN began in 1972 as a cooperative effort between Stanford University's medical and AI communities. This Expert System was developed for a very specific domain: the diagnosis and treatment of infectious blood diseases. Currently, Expert Systems comprise a growing field of their own and are often considered to be the first marketable result of AI research.

Expert System Definitions

"An Expert System is a computing system capable of representing and reasoning about some knowledge-rich domain . . . with a view to solving problems and giving advice."[4] While this is a general definition of an Expert System, there are a few specific features by which Expert Systems can be identified. These features are 1) a reliance on expert knowledge to make decisions, 2) the ability to provide explanations of decisions reached by the system, and 3) a clear separation of the knowledge base and the inference mechanism.

Expert knowledge is a rather obvious requirement for an Expert System. During the development of an Expert System, the accumulated knowledge of one or more experts in the chosen field must be collected and translated into a format understandable to the Expert System through a process known as knowledge engineering. A variety of knowledge representation schemes are available to the knowledge engineer, each of which is best suited to a particular class

of domains. More detailed descriptions of the most common knowledge representation schemes are presented in the "Knowledge Representation" section of this chapter.

Expert systems must also be able to explain the reasoning behind their decisions. Theoretically, Expert Systems are provided with expert knowledge on a specific domain in order to assist non-experts in the decision making process related to that domain. As a result, the user may not understand the results or may be skeptical about the results derived by the Expert System. Therefore, the Expert System must be able to explain how it reached its decision and, ultimately, to convince the user that its decision is indeed correct.

Finally, another common feature of an Expert System is the separation of the knowledge base and the inference engine. While not considered a requirement for an Expert System, this functional separation provides the system with greater flexibility. For example, the knowledge base can be expanded without affecting the inference engine or vice versa. This division also allows a developer to construct the knowledge base of an Expert System without having detailed knowledge of the inference engine. Thus, the separation of the knowledge base and the inference engine gives rise to a class of Expert System development tools known as Expert System shells which provide an inference engine, but leave the development of the knowledge base to

the developer. Several Expert System shells are described in the "Expert System Shells" section of this chapter.

As Expert Systems become more widely used, there is an increase in the number of tools available for their development. Selection of the proper tool for the chosen domain is becoming progressively more difficult. While the overall features provided by different tools vary, certain basic features, like an inference engine and a knowledge representation scheme, are essential. An understanding of these features would aid in the selection of the proper tool for the task. What follows is a discussion of the general features of an Expert System, followed by a more detailed examination of a few Expert System development tools.

Expert System Components

The two principal parts of an Expert System are the inference engine and the knowledge base and, as stated previously, a clear distinction between the two is usually maintained. The knowledge base is further divided into two parts based on the types of information being represented, namely facts and rules. In addition to these main modules, an Expert System may have any number of tools associated with it which perform various utility functions. Typical tools include an editor, a graphics interface, and an external program interface.

Inference engine. The inference engine is the working mechanism of the Expert System. The inference engine must

link the known facts to the rules and, according to the reasoning scheme being employed, execute the appropriate rules. When the needed information is not contained within the data base and cannot be derived by the rule base, then the inference engine must ask the user for the information. Display and explanation of the results are also the functions of the inference engine. Thus, all of the active functions of the Expert System are controlled by the inference engine. Since the inference engine just manipulates the information that it is given, the same inference engine can be applied to any number of domains, and any number of inference engines can be applied to the same domain.

Knowledge base. The knowledge base, on the other hand, is both static and unique to each Expert System. First, the knowledge base is static in that it does not perform any actions. The knowledge base contains the encapsulated expertise of the domain expert(s) but, while it can be expanded and improved upon, this body of knowledge cannot reach any conclusions on its own, i.e. it is data. It is the function of the inference engine to draw the conclusions based upon the information in the knowledge base. Second, the knowledge base is unique to each application. The domain knowledge can be represented in a variety of ways depending on the representation scheme being used, but the knowledge itself is constant. Furthermore, two different experts may have different approaches to the same problem

which results in different sets of rules for the domain. Nevertheless, the facts and conclusions of both approaches should be the same, so the two knowledge bases are functionally identical. Thus, the application is defined by the knowledge base and vice versa.

The expertise contained within the knowledge base can be subdivided into two categories: procedural knowledge and factual knowledge, commonly referred to as rules and facts, respectively. The facts represent what the system knows to be true and false about the domain. "Palisades is a Combustion Engineering reactor" and "BWRs use cruciform control blades" are examples of facts that the system might know. These facts are used by the inference engine to judge the rules during execution. Depending on the results of the comparison, the rules may "fire," i.e. be executed, which would then derive other facts. The body of facts known to the system will generally increase as the execution proceeds and new facts are derived. It is the goal of the inference engine to make these facts fit a pattern which will achieve the desired end result.

The rules, on the other hand, provide the procedural knowledge required by the inference engine by delineating the actions that the system can take to derive additional facts. Examples of possible rules for a system are "If the ^{94}Nb content is greater than 0.2 curies per cubic centimeter, then the waste is GTCC" and "If the component has reached its design lifetime, discharge and replace it."

The facts derived in this way can then be used to judge other rules and derive additional facts. Eventually, the rules should derive a fact which satisfies the system's goal, thus ending program execution. Generally speaking, the rules are not increased, decreased, or altered in any way during execution.

Other tools. Among the various tools frequently associated with Expert Systems, an editor is perhaps the most common. In most Expert Systems, an editor is provided to aid the developer in translating the knowledge into the representation scheme used by the Expert System. The type of editor provided and the way in which it is used by the Expert System often varies considerably. For example, Exsys[5] and RuleMaster 2[6] are two commercially available Expert System shells which use quite different editors. The Exsys editor is a completely self-contained, menu-driven package which is used to encode all of the domain knowledge. No other editors are necessary or possible. In contrast, RuleMaster 2 allows the developer to utilize any editor which can produce pure ASCII files, i.e. files containing only text without control codes or any other "hidden" characters. The programmer is then responsible for encoding the knowledge into Radial, the language used by RuleMaster 2 for knowledge representation. Thus, the RuleMaster 2 shell allows a wide range of editors, but requires the programmer to encode the knowledge while the Exsys shell requires the

use of the provided editor which encodes the knowledge itself.

Other possible tools include a graphics interface and an external program interface. Some of the high-end Expert System shells provide a graphics interface or even a graphics editor which allows the Expert System to express its results in a graphic format. An external program interface is more common, but also more limited. The interface allows the Expert System to access data stored in other file formats, usually dBase and Lotus 1-2-3, and to execute external programs. In the first case, the interface is usually limited to a few simple read and write functions while in the second, available memory is usually the limiting factor.

Collectively, the knowledge base, the inference engine, and any associated tools comprise the Expert System. The knowledge base is specific to the particular application, so it must be generated by the user for the specific task at hand. The inference engine and the tools, on the other hand, are interchangeable and can be used for multiple Expert System applications. This has produced a growing market in Expert System shells and other tools with which to construct an Expert System.

Knowledge Representation

A variety of knowledge representation schemes are available to the developer, the two most common of which are

the rule-based system and the frame-based system. A third representation scheme which is a derivation of the rule-based system is the example-based system. Of the three, the rule-based system is the best known because it emulates the thinking and structure of knowledge used by the expert. In a rule-based system, the knowledge is translated into a series of production rules of the IF-condition-THEN-action format. The resulting knowledge base is most closely represented by a tree structure or a flow diagram.

Frame-based systems are object-oriented and best represent domains dealing with physical objects or states. Each frame represents an object or state and contains several attributes which apply to that object or state. The attributes can either describe features which are intrinsic to that particular object or they can describe another object in a separate frame. When an attribute of one frame describes a second frame, the attributes of the second frame are inherited by the first. For example, Figure 15 shows the two frames "BWR Reactor" and "Peach Bottom Unit 2." The

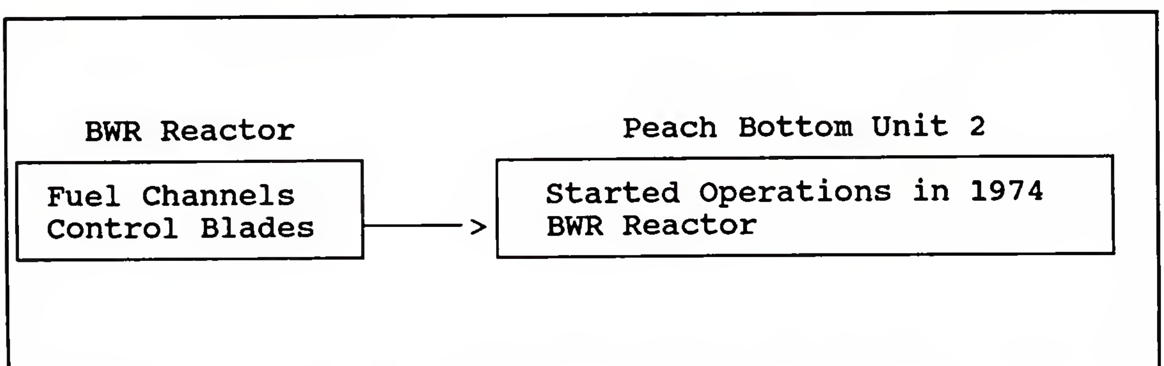

Figure 15. An example of frames and inheritance.

BWR Reactor frame has the attributes "Fuel Channels" and "Control Blades" which in this case describe intrinsic features of the object "BWR Reactor." The object "Peach Bottom Unit 2" has two attributes, "Started Operations in 1974" which is intrinsic and "BWR Reactor" which describes the other frame and causes Peach Bottom Unit 2 to inherit the attributes of the BWR Reactor frame. Thus, the Expert System infers that Peach Bottom Unit 2 has "Fuel Channels" and "Control Blades."

Finally, example-based systems are most suited to areas with an accumulation of past experience to rely on and numerous example decisions on which to base the knowledge. The typical example-based system will use the examples provided to derive rules very much like those in a rule-based system, but some systems will use an execution style more closely resembling a table-lookup scheme. Example-based systems are typically the easiest to develop and the least sophisticated in execution.

Reasoning Schemes

An Expert System must have a reasoning scheme by which to draw conclusions. One of two reasoning schemes, forward chaining and backward chaining, is usually used by an Expert System, but in a few cases an Expert System may use both in combination. Selection of the correct reasoning scheme for the domain being studied can greatly improve the system's efficiency. Generally, the Expert System should search from

the smaller search space to the larger search space, as the larger target is easier to hit. This means that if there are more possible solutions than possible starting points, forward chaining should be used. Conversely, if there are a limited number of goals but a large number of starting points, backward chaining is more appropriate.[7] More detailed descriptions of the two searching methods can be found below.

Forward chaining uses a "blind" approach, beginning with the known facts and using them to determine the order in which the rules are to be executed. The known facts are compared to the left sides of the rules (the IF portion of an IF-THEN rule) and those rules which are true are executed. The results of these rules, i.e. more known facts, are used to execute other rules until a goal is reached. Forward chaining is said to be "data directed," because the current data determines how the execution will continue. Forward chaining will terminate with the first solution derived, which is not necessarily the best solution. This method is generally slower than backward chaining as the system explores several solution paths simultaneously, but the method is exhaustive and will cover all possible approaches to the problem. Forward chaining is often useful for problems in which any solution is acceptable or all possible solutions are equally acceptable.[8]

In contrast, backward chaining is "goal directed" because the system begins with a goal and attempts to prove it true. One of the many possible goals, usually the first goal in the list, is chosen as the first goal the system desires to prove. The system matches the right side of a rule (the THEN portion) to this goal and then attempts to prove the left side of the rule by the same procedure. Execution continues until the left sides of the rules are matched to the initial starting data, thus proving the goal, or until all methods of proving that particular goal are exhausted, in which case the system will attempt to prove the next possible goal by the same methods. This scheme displays the advantage of decomposing a large problem into several smaller problems which are easier to solve, resulting in smoother, more efficient system execution. Backward chaining also allows the goals to be listed in the order of their desirability. The system will attempt to prove the first, most desirable goal before any of the less desirable ones.[9]

As a final note, while the terms forward and backward chaining and forward and backward reasoning are used almost interchangeably, there is a slight difference between the two. Chaining refers to the actual "chain" of rules developed by the system during execution, and thus to the way in which the rules are implemented. Reasoning refers to the developmental methods and strategies used by the Expert System designer, and so to the way in which the rules are

organized. Therefore, reasoning represents the theory of design, while chaining represents the actual execution.[10]

Expert System Shells

There is a wide range of tools available to aid in the development of a new Expert System. The features of these tools as well as the means by which they are employed vary. In general, these tools can be divided into the following three broad groupings: programming languages, programming environments, and Expert System shells. Which type of tool is appropriate for the task is dependent upon the chosen domain, the skills of the knowledge engineer, and the amount of customizing desired.

A programming language requires the most effort of the developer as the Expert System development is treated the same as the development of any other software program. All of the functions of the Expert System must be built from scratch. Several specialized AI languages are available to the programmer, the most common of which are LISP and PROLOG. Dedicated AI hardware has also been developed which is able to handle a large AI program efficiently, but these systems are very expensive and lack portability. Instead, many programmers are choosing to develop their packages using standard computing languages such as FORTRAN, PASCAL, and C which are more portable and, particularly in the case of C, much faster than the AI languages. The programming language approach is the most flexible of the development

methods as all of the Expert System functions and the knowledge representation are custom built for the specific application.

The second approach is the programming environment or "tool box" approach. The programming environment is intended to provide the developer with a set of "tools" to assist in the Expert System development. A low-end tool kit would contain a set of small, self-contained programs (called tools) which provide commonly used Expert System functions while a high-end programming environment might include an editor, a large package of tools, and perhaps even a special programming language. The Tool Box approach relieves the developer of some of the programming burden by providing a large number of frequently used functions, but the overall system design and program creation are still required. This places greater demands on the Expert System developer, but provides for a flexible system which can be customized to suit the particular application.

The most advanced, but potentially most restrictive, route is to choose an Expert System shell. An Expert System shell lacks only the specific domain knowledge to make a functional Expert System. All of the working parts of the Expert System, particularly the inference engine, are provided by the shell. Of course, the features provided by the Expert System shells show considerable variation. A low-end shell would provide just a simple inference engine and require the use of an external ASCII editor while a

high-end shell will include some or all of the following: its own editor, support of external editors, an advanced inference engine with at least one confidence system, an external interface (for Lotus 1-2-3, dBase III, and possibly others), customized I/O, graphics capability, and a compiler to produce a final integrated package. Thus, Expert System shells are designed to relieve the developer of the programming tasks so as to facilitate efficient development of the knowledge base itself.

The shell approach was selected for the development of the HWES. The following features were expected of any shell used for the development of the HWES: support of both forward and backward chaining, the ability to run external programs during Expert System execution, the ability to perform a large number of numerical calculations, and direct access to dBase files. An analysis of the Expert System shells examined during the course of this work are presented below.

Exsys

The Exsys shell, produced by Exsys Inc., was chosen for the initial development of the HWES. Exsys supports both forward and backward chaining, singly or in combination. The shell is rule-based and supports basic calculations and basic external program interfacing. The shell's features seemed to match the essential criteria of the HWES.

While programming the prototype version, a more in-depth analysis of the shell was conducted which uncovered certain strengths and weaknesses within the shell. The rule editor is fairly easy to use, but extremely limited from a text editor viewpoint. The editor is particularly cumbersome when working with a long section of text such as the introductory text or a long rule. At first glance, the result explanations and rule displays are appealing, but detailed examination generally proves to be confusing. Moreover, the shell exhibited two major shortcomings which impacted unfavorably upon the future development of the HWES. First, Exsys appeared to be too "goal-oriented." For most applications, the primary function of the Expert System is to aid the user in making a selection among various choices. Exsys was designed with this purpose in mind. However, the primary goal of this application is to display the results of various calculations based upon the user's choices. Exsys proceeded directly to the goal as designed, but not all of the desired calculations were being performed before this goal was reached, with the result that program execution stopped before the design goals of this application had been met.

Additionally and most importantly, the interface between Exsys and dBase could not access the dBase files directly. The interface could only invoke the main dBase program which presents two difficulties. The first difficulty is the requirement that both Exsys and dBase be

in the computer's memory at the same time. In the early stages of development, there was sufficient memory to handle this situation, but in later development stages memory shortages were experienced as a result of programs even smaller than dBase. The second and more important problem is that this type of interface depends too heavily on the actions and knowledge of the user. In order to extract the needed data and return it to Exsys, the user must have functional knowledge of dBase, of the CDB files and file system, and of Exsys itself. An alternative approach would be to provide the user with lengthy, detailed instructions on navigating through dBase, locating the proper file, extracting the proper data, and transferring the data to Exsys in the appropriate format. Both of these approaches are contrary to the goal of making a simple, easy-to-understand Expert System, so for these reasons, another shell was sought.

RuleMaster 2

The Radian Corporation's RuleMaster 2 shell was the second shell examined. This shell also supports forward and backward chaining and external interfaces. RuleMaster 2 is an example-based system, but does allow for the writing and implementation of rules using its unique programming language, Radial.

The RuleMaster 2 Expert System shell has some attractive features, but also possesses some serious

shortcomings. The user interface is not as attractive as that of Exsys. RuleMaster 2 relies heavily on its example-based systems for the development of rules, but since a major portion of the HWES is performance of calculations, the example-based format is not suitable. Direct coding of the rules did not prove to be an easier solution since the rules must be written in the Radial language. Radial is a fairly simple language containing only a few commands and structures, but the language's abilities are limited and the code, once written, is difficult to interpret. The Radial language does allow some flexibility in the rules that is not found in Exsys, but this slight advantage is countered by the necessity of learning the Radial language in the first place.

RuleMaster 2 is also a compiled system, meaning that the Expert System must be compiled before execution. During program development, compilation is generally a nuisance as even the slightest change to the code (the knowledge base, in this case) requires that the program be re-compiled. However, for the final product, compilation is generally an outstanding feature as it increases program execution speed. Unfortunately, while the RuleMaster 2 documentation is fairly good and does explain the necessary steps to compile an Expert System, the error conditions that might result during compilation are not explained.

During the early programming efforts of the HWES, several compilation errors were encountered. Since these

errors were specific to RuleMaster 2 and not a function of the compiler, they were not explained by the compiler manuals either, which made it impossible to isolate and correct the problems. Consultation with the Radian Corporation should have made it possible to isolate and correct these difficulties, but other problems with RuleMaster 2 forestalled these efforts. The dBase interface of RuleMaster 2 was identical to that of Exsys and, therefore, not suitable to the application. Thus, another shell was required.

Exsys Professional

Since the initial efforts with the Exsys shell, Exsys Inc. had announced the release of another Expert System shell, one which has expanded upon the original Exsys shell. This package, Exsys Professional,[11] expanded upon the Exsys shell with several additional features, two of which are particularly important. First, Exsys Professional gives the developer increased control over the rule execution and the report format which, when combined with an element of forward chaining, eliminates the excessive "goal-orientation" problem exhibited by Exsys. Second, Exsys Professional provides four functions for the direct access of dBase file, thus "hiding" dBase and the dBase files from the end user. These features eliminate the primary objections to the Exsys shell; therefore, Exsys Professional

was selected for the development of the complete Expert System.

During the Expert System development, several other features, both good and bad, became apparent as did the lack of certain other features. As noted earlier in regards to the Exsys shell, the text-editing capability of the rule editor is limited, so the inclusion of a rule compiler is a beneficial addition. The compiler converts rules written with an ASCII editor into Exsys Professional format, thus permitting the use of an external editor for more efficient rule correction and manipulation. On the negative side, the results output screen, while adequate for short answers, is confusing when displaying lengthy results. The lack of output formatting prevents the trimming of insignificant digits from numerical results, with the result that numbers have an excessive number of digits. For example, even a zero result is displayed to 15 decimal places. Only the most basic string and numeric functions are included within the shell, requiring external programs to perform even common functions like sub-strings. While many of the difficulties are trivial, such as the lack of arrays, others proved to be extremely limiting, such as the failure of Exsys Professional to adequately handle a large numbers of external calls (see the "Conversion: Version 2" section of this chapter).

<u>Other Shells</u>

Several other Expert System shells and Expert System development packages were also examined for potential application to the HWES. The information presented here was extracted from reviews in the literature, sales brochures from the individual companies, or in the case of EMYCIN, from programming experience with the shell. The shells reviewed range in sophistication from very basic (EMYCIN) to very complex (GURU). All software packages are reviewed for use on IBM PC personal computers.

<u>EMYCIN</u>. EMYCIN[12] is a shareware program available free or at minimal charge through a number of sources. EMYCIN was derived from the MYCIN Expert System discussed earlier in the "Expert System" section of this chapter. By removing the domain knowledge from MYCIN, EMYCIN or "Empty-MYCIN" was created. EMYCIN is written in LISP, supports only backward chaining, and contains only the most basic functions. Any more advanced functions must be developed by the developer. Accordingly, EMYCIN is just barely above a programming language in sophistication and will require a good deal of customizing to complete an Expert System.

<u>GURU</u>. The GURU shell[13] is produced by Micro Data Base Systems, Inc. and is one of the most complete Expert System shells offered for the IBM PC. The shell is a rule-based system which offers both forward and backward chaining and uses compiled rule sets for improved execution. Written with a combination of C and assembly language, GURU claims

to readily accept customized functions written in these languages. The shell supports direct access of dBase files and GURU spreadsheets. Lotus 1-2-3 data can also be accessed if it is first imported into a GURU spreadsheet. Both input and output from the GURU shell can be customized to suit the user's application, and a variety of graphics including pie charts and line graphs can be used throughout the system's execution. GURU also offers numerous additional features including advanced math functions, advanced string functions including a sub-string function, the use of arrays, and support of wildcards and boolean functions. GURU is clearly a high-end shell for the development of powerful Expert Systems.

1st-Class Fusion. The 1st-Class Fusion[14] shell is a median-level shell by 1st-Class Expert Systems, Inc. Fusion, like RuleMaster 2, offers the developer both a rule-based and an example-based development scheme, but without actual experimentation with Fusion, it is unknown how well these two schemes are realized. As with most shells, both forward and backward chaining are supported. The shell offers direct access to dBase files, but unlike most shells which only offer a read/write interface, Fusion also offers an append function. Furthermore, the brochures claim that these actions are performed using dBase commands which offers the potential for greatly increased programming flexibility. Perhaps the most unique feature of Fusion, however, is the ability to convert the completed Expert

System into C or PASCAL source code. Using this conversion, the Expert System can be directly imbedded into another program instead of operating as an external call, thus greatly increasing the portability and efficiency of such a system.

SuperExpert. SuperExpert[15] is an inexpensive, low-end shell produced by Softsync, Inc. which is solely example-based, so no direct rule editing is possible. The examples can be entered directly into a spreadsheet-like environment provided by SuperExpert or they can be imported from Lotus 1-2-3 or dBase. SuperExpert supports both forward and backward chaining, and has a spreadsheet interface for use within applications, but does not support any database interface capability (other than for importing examples).

Level5. Information Builders, Inc. produces an Expert System shell called Level5[16] which falls in the mid-range of Expert System shells. Level5 is a rule-based system which uses a proprietary Production Rule Language (referred to as PRL) for the knowledge encoding. The PRL is designed to use English syntax to increase the ease of knowledge base development. Level5 supports forward and backward chaining and includes "goal outlining" which permits the goals to be organized into a logical sequence for search purposes. Like many of the other shells, this shell also provides direct dBase file access, but Level5 additionally claims that no special programming is required to implement this interface, i.e. the data access is automatically implemented within the

syntax of the rules. No mention of a spreadsheet interface is made.

VP-Expert. The final shell examined by the author was VP-Expert[17] by Paperback Software. The shell supports forward and backward chaining and is nominally a rule-based system, but includes an inductive reasoning device which can derive rules from a set of examples. The rules are written either with the built-in text editor or with any ASCII editor. VP-Expert supports graphics primitives like circles and rectangles for use within the applications, a feature normally found only in high-end packages. The shell can directly access dBase files for reading, writing, and appending, and supports indexed files, but the exact nature of the index support is unknown. VP-Expert also includes two other unique features. The first feature is a set of dynamic "meters and gauges" which can be linked to a group of variables and will rise and fall as the consultation progresses to dynamically illustrate to the end user the effects of his actions and choices. The second feature is mouse support within the application which greatly enhances the user interface. VP-Expert thus features several high-end functions for the price of a low- to middle-end product.

Prototype: Version 1

The Expert System designed, implemented, and studied in this work is an expansion of the Expert System prototype developed previously for the author's Master's Degree

project. Whereas the currently running version of the Expert System bears little or no resemblance to the prototype, the prototype was used in the initial development stages and therefore should be reviewed.

The prototype Expert System was developed with the Exsys shell as its foundation. The prototype's knowledge base was specifically tailored to the Palisades reactor. The data needed to perform the calculations was hard-coded into the variables. Roughly two-thirds of the Expert System's variables were occupied by this data. Two small external programs written in BASIC were also used to provide needed functions not included in the Exsys shell. Upon completion, this prototype was capable of calculating the quantities and weights of NFA hardware generated at the Palisades reactor, as well as performing rudimentary 10CFR61 classifications for this hardware. At the time of the development of the prototype, however, those calculations were not considered to be a primary function of the Expert System. As a result, greater attention was given to the calculation of SFD hardware weights resulting from potential spent fuel rod consolidation campaigns at the Palisades reactor. The calculated weights were divided into GTCC wastes and LECC wastes, with LECC wastes being any waste which fell into the Class A, B, or C categories.

Since this program was just a prototype of the HWES, major alterations were required to develop the complete Expert System package. For example, the prototype needed to

be upgraded to Exsys Professional and the existing rules completely revised to increase the program's flexibility, to broaden the program's scope, and to take full advantage of the advanced functions of Exsys Professional. The major thrust of the Expert System was also altered at that time. New information had indicated that the performance of NFA hardware calculations should be emphasized over the performance of SFD hardware calculations.

Conversion: Version 2

The first modification to be performed on the HWES prototype was the conversion to Exsys Professional, including the elimination of hard-coded data. Program files generated with the Exsys shell are fully compatible with the Exsys Professional shell, so that the literal "conversion" from one shell to the other merely involved loading the existing files into the Exsys Professional shell and was thus trivial to perform. The implementation of the more advanced functions of the new shell in preparation for the system's expansion and the elimination of the hard-coded data were the true intents of this phase of the dissertation.

As stated earlier, two-thirds of the prototype's variables were actually used as constants to contain information specific to the Palisades reactor. These constants contained information on the reactor, the NFA hardware, and the SFD hardware. Once the HWES was fully

implemented, the Expert System would be expected to extract this data directly from various dBase files. Thus, the program conversion required that all of these variables be converted from hard-coded constants to dBase calls. Exsys Professional included two dBase functions which could handle many of the data calls. The db_gn function reads by record number while the db_gk function reads by file index. These functions, however, proved insufficient to handle the remainder of the data calls, so a specialized function was developed.

The db_gn and db_gk functions perform adequately in cases involving single, uniquely defined records. However, on several occasions the HWES is required to read several different records which share a common characteristic. One of the more prominent examples of this is the input of the required NFA hardware information for each reactor under study. Each reactor has from 0 to 19 different NFA hardware elements listed within the CDB's data files, with most reactors having more than one record. Table 17 shows a breakdown by vendor of the number of NFA components listed at the reactors and the number of reactors with those hardware quantities. Each reactor listed within the CDB has a number of NFA hardware types known to be associated with it, as well as a number of hardware types which are assumed to be associated with it. Each combination of known and assumed quantities is listed in the table along with the number of reactors which exhibit that particular

Table 17. A breakdown of the number of NFA hardware records associated with the reactor records within the Characteristics Data Base (CDB).

Ven dor	Number of Reactors	Number Known Components	Num. Assumed Components	Total Listed Components
B&W	4	5	2	7
B&W	3	4	3	7
B&W	1	6	1	7
CE	14	4	0	4
CE	1	3	0	3
GE	18	1	0	1
GE	15	2	0	2
GE	3	0	1	1
GE	5	0	2	2
W	10	0	15	15
W	33	0	19	19
W	1	0	16	16
W	6	0	18	18

combination. (See the appendices for listings of the actual NFA hardware components associated with each reactor.) Furthermore, the table shows that there is a strong correlation between the number of components listed and the reactor vendor. In addition to the variable number of records, the types and names of these elements vary from one reactor to another, making it impossible to provide information which would be sufficiently specific for the db_gk function to locate all of the records. However, since the records share a common characteristic, the records are grouped sequentially in an index file, and thus are

theoretically easy to locate using a sequential read function.

The program "NFAREC.EXE" was written in the C language to perform this sequential read for a variable number of records. The program was designed to receive the same information required by the db_gk function, but instead of returning actual data items, the program would perform a sequential read of the index file to locate all of the records which matched the given profile and would then return a list of the record numbers for these records. These record numbers would then be used in conjunction with the Exsys Professional db_gn function to read in the desired information for all of the reactor's hardware elements. The NFAREC.EXE program was written specifically to read NFA hardware records for a given reactor, but was designed as a sub-routine which allowed the function to be used later in other programs for other sequential read applications.

Two other C language programs were also required. The first program was called RNAMES.EXE and was used to select the name of the reactor which was to be studied. This program will be described in greater detail in the next section. The second program was required due to a deficiency of the Exsys Professional shell. Exsys Professional did not provide a sub-string function; therefore, it was necessary to develop one externally. The TRIM.EXE program was written to provide this capability.

Further development of the HWES Version 2 was prematurely terminated at this stage. At this point, the program was capable of estimating current NFA hardware inventories at any Combustion Engineering reactor, or any other reactor with four or fewer NFA hardware types. In total, this ability accounted for the 16 Combustion Engineering reactors and 40 General Electric reactors, thus representing approximately 44% of the total reactors contained within the CDB files. The conversion from Exsys to Exsys Professional had been completed and all hard-coded data had been removed. The structure of the Expert System was as illustrated in Figure 16.

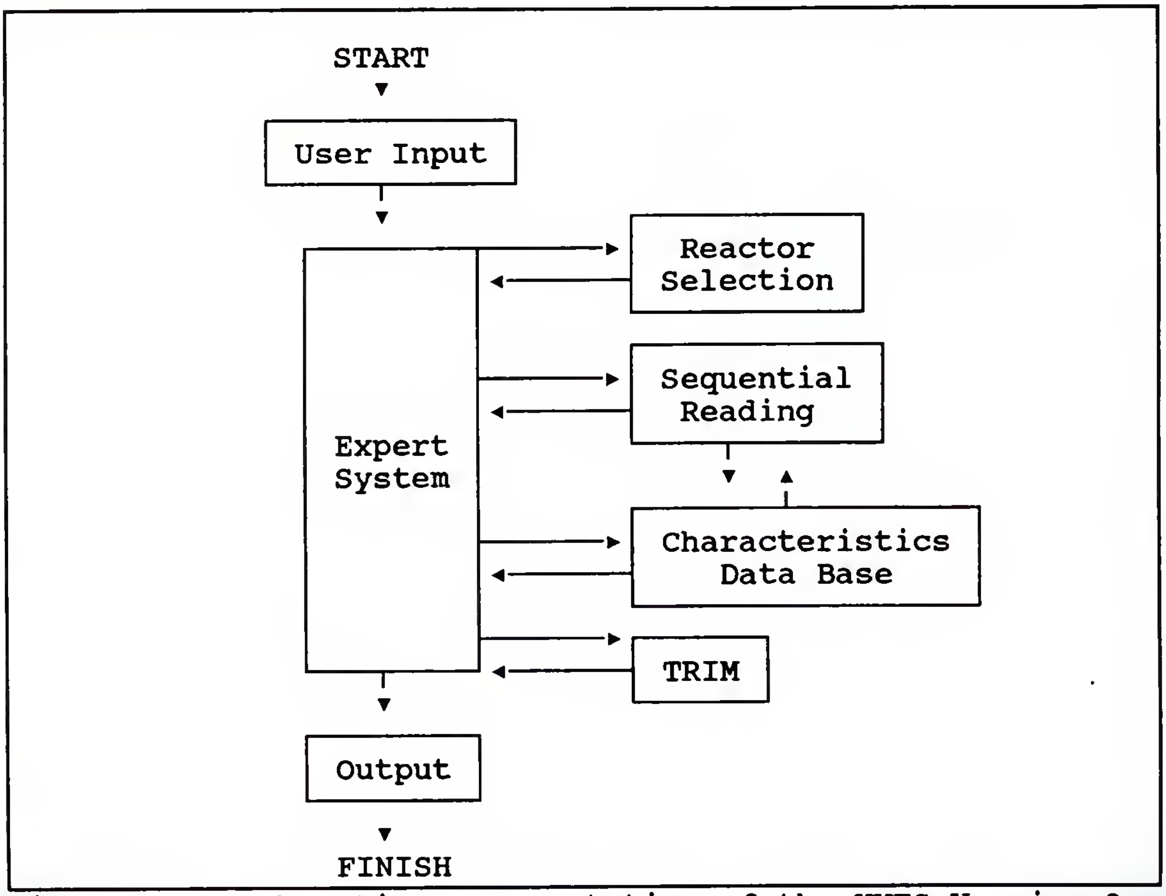

Figure 16. Schematic representation of the HWES Version 2.

At this point, however, a serious problem with the Expert System and its external interface occurred which prevented further development of the program. In the course of execution, the Expert System was required to make several external calls, mostly to dBase files for data, but also to the RNAMES and TRIM programs. A typical execution involving four NFA components required approximately 12 such calls. The first program run of the session usually executed without difficulty, but a re-run or any subsequent executions proved to be impossible. During subsequent executions, the Expert System failed to perform external calls and instead would ask the user for the necessary information, information which the user would be unable to provide. To run the system again required that the user exit from Exsys Professional entirely, i.e. return to DOS, then reload the shell and program. Once reloaded, the Expert System would again be able to be executed a single time.

Apparently, Exsys Professional could only handle a total of about 10 to 15 external calls over the duration of the execution. There were two likely explanations for this phenomenon. The first suggested that Exsys Professional had a limited number of file handles and that each file handle could only be used once. Once the handles were exhausted, the Expert System no longer performed external calls. The second explanation was that Exsys Professional was limited by the available memory space. Each external call required

that a program or function be loaded into memory and once the memory was exhausted, no additional external programs could be executed. In neither case was Exsys Professional performing in a manner consistent with other programs. In a standard program, when an external call is executed, the other program is temporarily loaded into memory and temporarily associated with a file handle. When the external call is completed, the program is unloaded and the file handle is freed for re-use. Accordingly, standard programs are only limited in the number of external calls they can handle simultaneously, not sequentially.

This problem represented a critical obstacle to the further development of the HWES. Neither the single execution per loading or the limited Expert System abilities were acceptable for the final product. Furthermore, the expansion of the Expert System's abilities to include a greater variety of reactors, reactor hardware, and types of estimates would all lead to an increase in the number of external calls. This increase was likely to have created a situation in which even a single complete execution of the Expert System would not have been possible.

Consultation with Exsys Inc. personnel proved that the second assumption was indeed correct. A problem with their C compiler resulted in the db_gk and db_gn functions not freeing up memory when instructed to do so. The result was that only ten to twelve executions of these functions were possible before an error occurred. This difficulty was

later corrected in Exsys Professional Version 2, but the decision was made to proceed with the restructuring of the system nevertheless. This restructuring lead to the development of Version 3 of the HWES.

Refinement: Version 3

Several possible solutions to the problems presented by Version 2 of the HWES were available. One such solution to the immediate problem would have been to upgrade the shell to Exsys Professional Version 2. This would have solved the problem with the dBase functions, but several features yet to be implemented would have required external programming nonetheless. The second approach was to combine all of the small data gathering calls into one large data call. This approach would also have eliminated the external interface problem, and would make maximum use of the functions which were already programmed into the Expert System, but would also require extensive external programming to implement. For example, whereas the sequential read function for dBase files had already been developed, this approach would require the development of other dBase read functions as the Exsys Professional dBase functions could no longer be used in most, if not all, cases. Significant additional programming was also required; therefore, while this approach was considered a viable alternative, a more efficient approach was selected.

The final approach which was studied, and subsequently applied, sought to take maximum advantage of the required external programming. Instead of just grouping all the external calls into one large program, all the calculations were also removed from the Expert System and integrated into the same program as the data calls, thus resulting in only one large program for most of the system's functions. Since it was already necessary to group the dBase input functions externally, a process which would require a fair degree of programming, adding the calculations to the program did not represent a major additional programming burden. Finally, several simple tools for improving the output screens were readily available externally, thus helping to solve another problem. Thus, this approach was chosen as it proved an efficient means of solving several problems with one program.

As a result, the program's structure was completely revised. In Version 2, the Expert System had performed the majority of the calculations, but numerous external calls were needed for data gathering and data manipulation. With the development of Version 3, the Expert System assumed the role of the program controller. All of the small external programs and dBase calls used in Version 2 were combined into two large external programs which are called by the Expert System. The first program, SELECT.EXE, is used to select the name of the reactor or utility which is to be studied. The other program is HARDWARE.EXE which contains

all of the calculational functions and all of the dBase calls previously in the Expert System. The resulting system performs only two external calls in the course of execution. The structure of Version 3 is illustrated in Figure 17.

The final revision of the Expert System began with the elimination of all calculations from within the Expert System proper. The Expert System was now implemented as a forward chaining system and the system's new goal was to select a type of estimate. Once the system had gathered the necessary preliminary data, the results were passed to the HARDWARE.EXE program to perform the actual calculations.

Proper execution of these external programs was complicated by another peculiarity of Exsys Professional. The main body of the Expert System and the external programs

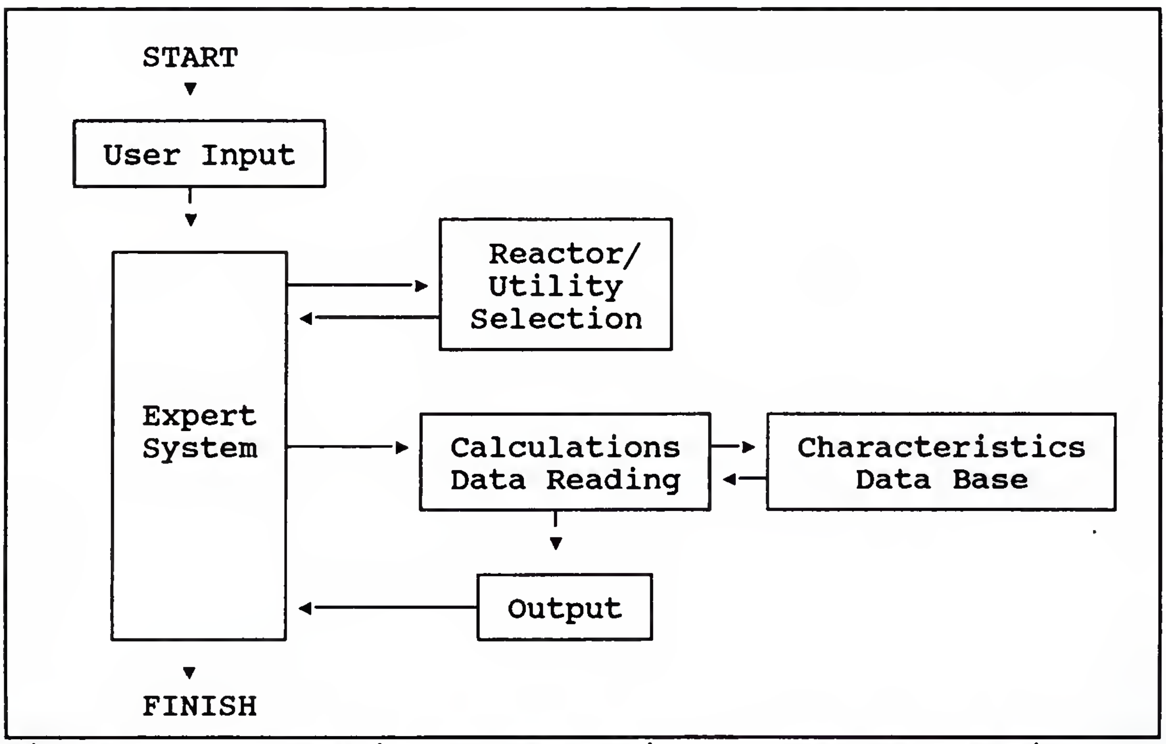

Figure 17. Schematic representation of the HWES Version 3.

it calls are too large to fit into the computer's memory simultaneously; therefore, it is necessary to run Exsys Professional in the batch mode. The Exsys Professional batch mode is designed to unload Exsys Professional from memory when an external call is made and to reload it after the external call is completed, thus allowing all available memory to be used by the external program. When Exsys Professional is unloaded, only that data which has been provided by the user or by an external program is saved. The data which Exsys Professional derived up to this point is discarded and then re-derived when the external call is completed. Accordingly, the external program must return a value to the Expert System which signifies that the program has been run or, upon re-deriving the data, Exsys Professional will reach the same conclusion as before, i.e. that the external program must be run again. If such a value is not returned, this loop will continue indefinitely. This is not clearly indicated in the documentation, but after consultation with Exsys Corporation staff, the problem was readily solved.

In Version 3, reactor and utility names are selected using the SELECT.EXE program. This program is an expansion of the RNAMES.EXE program and incorporates the routines needed for the selection of nuclear utility names. The reactor names are read from the RCTNAMES.DBF data file which contains only one entry per reactor, thus providing a simple listing without duplicate entries which can be used for the

selection menus. There is no similar file for utility names, however, so they are taken from the REACTOR.DBF file which also contains one record per reactor and thus a variable number of entries for each utility. Accordingly, after each name is read, it is compared with those already on record to prevent duplication. In either case, the names are then divided into groups of 20 and displayed in a scrolling bar menu for easy selection.

With the completion of the coding of the Expert System, emphasis was shifted to further development of the NFAPROG program. Upon the termination of work on Version 2, the NFAPROG could only read the NFA hardware records numbers. All other data gathering and calculations were performed by the Expert System. Under the new program structure, 95% of all the required data is read by NFAPROG. Since the Exsys Professional dBase functions could not be used from NFAPROG, equivalent functions were developed within NFAPROG. The Exsys Professional read-by-index function, db_gk, was replaced by dbRecn and the read-by-record-number function, db_gn, was replaced by dbReadn. These C functions are used extensively throughout the HWES's development.

These new functions, when used in conjunction with the sequential read function, dbReadsq, provide the capability for reading all of the data required by the Expert System. The use of arrays simplified the data handling and provided the variables needed to examine any of the 126 reactors in the CDB. Implementation of the calculations for number,

weight, cubic volume, reduced volume, and radiation classification completed the NFA hardware portion of the code. At this stage, NFAPROG could perform any type of estimate for the NFA hardware of a single reactor.

During the development of this code, a decision was required as to how to estimate the rate of discharge of the NFA hardware components. The hardware lifetimes provided in the NFA Hardware Data Base are the theoretical lifetimes of the hardware as specified by the hardware vendors. In general, all NFA hardware components of any particular type are installed more or less simultaneously during plant construction. Accordingly, if all of the components are subjected to the same environment, all hardware components of a particular type should also wear out and be replaced at the same time. In this case, the rate of discharge would be modeled as a step function, with entire hardware batches being replaced simultaneously at even intervals of the hardware's lifetime. Conversely, there are a number of reasons why this might not be the case. For example, some components may fail prematurely, or the components could be replaced early due to preventive replacement or backfitting. Furthermore, most component lifetimes are given in terms of EFPD (Effective Full Power Days) in which case those components near the edge of the core may not wear out as quickly as those at the center of the core. Based on these criteria, the discharge rate would be better modeled by a linear function.

Initially, the step function was selected. Some preliminary data from utilities was examined and it was found that the components are frequently discharged in batches. However, further examination revealed that these batches typically only represent a portion of the total number of any particular type of component. As calculations using the linear discharge rate are generally in close agreement with the utility data, the linear model is currently used in the Expert System. An examination of the accuracy of this model is presented in the next section of this chapter.

The next obstacle was to convert the current program, which could examine a single reactor, into a program capable of handling multiple reactors sequentially. To accomplish this goal, a new controlling program, HARDWARE, was developed which calls NFAPROG as a subroutine. To implement the examination of multiple reactors, the HARDWARE program generates an array containing all the desired reactor names and then passes one name at a time to NFAPROG in a loop structure. This method provides added flexibility to the system through the use of the HARDWARE program and eliminates the necessity of altering NFAPROG.

The final step in the development of the NFA hardware functions was to produce an efficient, easy-to-read output screen format. This was accomplished with the Saywhat program developed by The Research Group.[18] The Saywhat program is designed to easily create screens using the IBM

extended ASCII characters. Screens created with Saywhat are displayed by using the included Terminate-and-Stay-Resident program Vidpop.[19] By loading Vidpop before executing the Expert System, the customized screens can be called up by the HARDWARE program to provide the results screens. Additional utility and help screens were also developed with this program.

With the NFA hardware functions completed, the SFD hardware functions were implemented in SFDPROG which, like NFAPROG, is called as a subroutine of HARDWARE. For SFD hardware calculations, the assembly types to be consolidated must be known. Thus, the user is asked to select some or all of the displayed fuel assembly types for consolidation. The quantities of assemblies consolidated can be taken from the historical data or input by the user. Once the campaign is specified, the program performs the calculations and presents the output to a Saywhat screen. The final results of the SFDPROG subroutine include the generated hardware's weight, the fuel assembly skeletons' uncompacted volume, the minimum theoretical SFD hardware volume (based on material densities), and the maximum achievable compaction ratio based on these volumes. Also included are the number of assemblies consolidated, the number of spaces taken up by these assemblies after consolidation, the number of spaces required by the SFD hardware canisters (assuming a 10:1 compaction ratio), and the number of spaces made available for future use.

This completed the development of the HWES. In its final state, the program can only marginally be called an Expert System, and that is more a function of its origins than its results. The Exsys Professional Expert System shell was used for the development of the Expert System portion of the program. The Expert System is used as a controller to regulate the flow and to call the two external programs SELECT and HARDWARE. SELECT is used to select reactor and utility names while HARDWARE is the primary worker and provides all of the calculations and results output. The resulting HWES performs calculations of number, volume, weight, and 10CFR61 classification for NFA and SFD hardware. The SFD calculations are always performed for a single reactor, but the NFA calculations can be performed for one or more reactors with summary results produced for all reactors studied. All 126 reactors by the four major vendors as specified in the CDB can be examined. The results are presented in a concise manner and are equipped with a help facility to provide simply explanations of the categories. This fulfills the original design expectations of the HWES set forth upon the completion of Version 1.

Program Results

Upon the program's completion, three sets of data were generated. The first set is an estimate of the current hardware inventories throughout the industry. The second set estimates the total hardware inventory expected in the

year 2010, the most recent estimate of the repository startup date. The third and final set is composed of several SFD hardware/consolidation campaign estimates. A summary of the important points brought out by these data sets is presented below.

The first data set includes estimates of all NFA hardware generated through the year 1990 at the 126 reactors listed within the CDB. The complete 1990 estimate is presented in Appendix A. Eleven of the 126 reactors had not yet begun commercial operation, so no estimates were generated for them. Seven additional reactors had no NFA hardware information provided, so estimates were not possible for these reactors either. Of these seven reactors, most were either very early reactors, like Big Rock Point and Lacrosse, or new reactors which started operation after the development of the CDB, like the two South Texas units. Estimates were performed for the remaining 108 reactors, although the level of detail in these estimates vary. Table 18 provides a breakdown by vendor and reactor type of the reactors which are and are not included in the estimates. For the 38 General Electric reactors, only the number of fuel channels is estimated, because no other NFA hardware information is available for these reactors. For the 47 Westinghouse reactors, complete weight, volume, and classification calculations were performed. However, because it is unknown which NFA hardware elements are used at each reactor, and in what

Table 18. Breakdown of reactors, by vendor and reactor type, for which estimates were performed by the HWES.

	Total	Not Yet Commercial	Without Info.	Estimated
Allis Chalmers	1	0	1	0
Babcock & Wilcox	12	3	1	8
Combustion Engineering	16	1	0	15
General Electric	42	3	1	38
Westing-house	55	4	4	47
PWR	84	8	6	70
BWR	42	3	1	38
TOTALS	126	11	7	108

quantities those elements are used, no quantity calculations were performed for these reactors. For the Babcock & Wilcox and Combustion Engineering reactors, 23 reactors total, complete estimates were performed for the enumerated hardware elements.

Table 19 presents a summary of the NFA hardware quantities estimate for 1990. The results included in this table only include those hardware items for which all information was complete. If a single datum could not be calculated, like the waste classification, then the hardware item was not included in these totals. As can be seen from the table, only 23 out of 95 listed hardware items contain complete hardware information. However, for the majority of

Table 19. The total NFA hardware inventories predicted through the year 1990. (Weight is in units of Metric Tons while the volumes are in Cubic Meters.)

	Number of Types	Number of Components	Total Weight	External Volume	Reduced Volume
BWR Fuel Channels	1 of 7	29655	1200	2400	176
Control Elements	7 of 25	622	24	115	4.48
Gde Tube Plugs	0 of 5	0	0	0	0
Incore Instrum.	9 of 9	1316	7.4	1.16	0.972
Burnable Poisons	0 of 23	0	0	0	0
Neutron Sources	6 of 26	29	0.35	2.42	0.0228
TOTALS	23 of 95	31632	1200	2520	182

the hardware items not included in these figures, only one or two pieces of data are required to complete the records. Also, two of the three most important hardware categories in terms of overall volumes (BWR fuel channels and PWR control Elements--see the last section of this chapter for details) are already included in Table 19. Finally, the results presented here stem mostly from the Babcock & Wilcox and Combustion Engineering hardware information. The quantities derived from these records can be used to estimate the quantities for the Westinghouse hardware. Once the quantities are estimated, the other values already calculated for the Westinghouse hardware will complete the estimate. The results of this approximation are presented

in the last section of this chapter which is entitled "Hardware Waste Quantities." Estimates of the heat load represented by this hardware will also be presented at that time.

Before proceeding further, an explanation of the terms and results in Table 19 is necessary. First, the external volume is determined by the approximate external dimensions of the hardware elements and thus includes significant void volumes. Nevertheless, this is the volume that the hardware would occupy if it were stacked without any regard for space savings and thus represents an upper-bound figure. The reduced volume is the theoretical minimum volume to which the hardware could be reduced based on the actual metal weights and densities. This volume can only be achieved by eliminating all void spaces, i.e. by melting, and presents the lower-bound figure.

While the overall number of hardware types represented in Table 19 is limited, several key points can be made by examining the individual hardware types. First, both guide tube plugs and burnable poison rod assemblies (BPRAs) are conspicuous by their absence. The BPRAs are not included in the results because no information is provided in the CDB which specifies how many of these elements are used at each reactor. Since the number of BPRAs is dependent upon the core configuration which changes each cycle, a generic number cannot be specified. Guide tube plugs also suffer from a lack of information on how many are used in each

reactor, as well as a lack of a definable lifetime. In the first case, guide tube plugs are installed in PWR assemblies to prevent cooling water flow up the guide tubes. Accordingly, one guide tube plug is installed in each assembly which does not already have a source assembly, an instrumentation assembly, a BPRA, or a control rod assembly. As the configuration of the core changes from cycle to cycle, so do the number of guide tube plugs. In regards to hardware lifetimes, these components do not "burn out" like control rods or incore instrumentation, so they remain in the reactor until the reactor is decommissioned, at which time they are disposed of, or until they break, at which time they are replaced. However, the use of both BPRAs and guide tube plugs has been discontinued by most reactors. BPRAs have generally been replaced with burnable poisons which are integral to the fuel, while the bypass flow prevented by guide tube plugs is compensated for by other means. As a result of these factors, the only accurate means of quantifying these hardware types is by direct contact with the individual reactor sites.

In the case of BWR fuel channels, while only one type of channel is reflected in the final results, more than 50% of the BWRs for which an estimate was made (20 reactors total) are believed to use this channel type. Furthermore, for the remaining 18 reactors, the channels were not included in the final results because the waste classification could not be calculated. However, the

quantity, weight, and external volume of these channels was calculated and is included in the waste summary presented in the last section of this chapter.

Two points should be considered when examining the fuel channel values presented in Table 19. First, both the values presented in Table 19 and the overall values presented in the last section of this chapter, should be considered upper-bound figures. Since some utilities have already disposed of some fuel channels, and others have reused some channels for a second assembly lifetime, the actual number of fuel channels awaiting disposal should be less than these figures suggest. Since the extent of the implementation of these practices is unknown, how much lower the actual figures are cannot be determined at this time, but these values can nonetheless be used as upper-bound figures. The second point is that, should these channels require separate disposal from the spent fuel, it is possible to volume reduce these channels by more than a factor of ten through the use of melting. Even crushing/shearing operations should be able to reliably reduce the volume by a factor of five to ten. This result is significant in that BWR fuel channels are expected to represent the majority of all NFA hardware wastes.

For control assemblies, the seven types included in the final results represent the majority of the Babcock & Wilcox and Combustion Engineering control assemblies. The Westinghouse control rod assemblies as a whole lack

information on how many elements are used at each reactor, so they are not included in these figures. However, as has been previously mentioned, the values calculated for the other PWR vendors' assemblies can be used to estimate the Westinghouse quantities; the results of this estimate are included in the "Hardware Waste Quantities" section. Of greater importance is the lack of information on BWR cruciform control blades. These BWR control blades represent the largest hardware waste category which for which no information is included in the CDB. This hardware is also estimated, however, in the last section of this chapter.

All nine of the incore instrumentation records are reflected in the final results, but unfortunately, these records only represent the Combustion Engineering instrumentation. Nevertheless, the results show that incore instrumentation is likely to represent the second largest NFA hardware waste category in terms of numbers, but is not nearly so significant in terms of weight or volume. This is due to the fact that while these components suffer from a relatively short lifetime, the actual size of the components is rather small. Again, the values presented in Table 19 are used to estimate values for the reactors which lack specific information, the results of which are presented in the last section of this chapter.

Finally, the records for incore sources which are not reflected in the results are, as expected, the Westinghouse

source records which, again, lack information indicating the number in use at each reactor. These quantities are also estimated in the last section of this chapter. Table 19 does illustrate that incore sources are the smallest category of NFA hardware waste in both numbers and total weight. Since many reactors permanently discharge their incore sources after only a few cycles, large quantities of these components are not expected.

Table 20 summarizes the results of the second data set which details the hardware calculations to the year 2010. The complete 2010 estimate is presented in Appendix B. The data in the second set is similar in most respects to the previous calculations. Most importantly, the results

Table 20. The total NFA hardware inventories predicted through the year 2010. (Weight is in units of Metric Tons while the volumes are in Cubic Meters.)

	Number of Types	Number of Components	Total Weight	External Volume	Reduced Volume
BWR Fuel Channels	1 of 7	84051	3400	7040	517
Control Elements	7 of 25	1853	77	356	14.1
Gde Tube Plugs	0 of 5	0	0	0	0
Incore Instrum.	9 of 9	4253	28	5.08	3.72
Burnable Poisons	0 of 23	0	0	0	0
Neutron Sources	6 of 26	89	0.9	5.55	0.0675
TOTALS	23 of 95	90246	3500	7400	535

indicate that the hardware waste quantities should triple by the year 2010. Hence, plans for the waste's disposal should be developed and implemented now before these wastes become a serious storage problem for either the utilities or the federal government.

Both sets of calculations clearly show that the volumes of waste hardware can be significantly reduced be either melting or compaction. The values presented in the tables show volume reduction factors of ten or greater, based on melting the hardware. However, even crushing/shearing techniques should be able to achieve reduction factors of five to ten. The volume reduced hardware would be more efficient for handling and would represent a substantial monetary savings in all aspects of disposal. Of course, volume reduction is not required for any hardware which can be disposed of integral to the spent fuel assemblies.

Analysis of the results of the sample SFD calculations did not produce any significant results. The maximum theoretical compaction ratios provided by the HWES range from 40 to 50:1. The HWES calculations are based on the number and types of SFD hardware components specified for each assembly as listed in the CDB. The compaction ratio is calculated by estimating the minimum possible volume of the hardware based on the hardware's materials of composition and the material's elemental density. Since the only practical method for achieving theoretical density is melting the hardware, these results are expected to serve as

a lower reference case. Most consolidation programs reduce the hardware by crushing and shearing which, regardless of the efficiency of the system, will leave void spaces and cannot exceed the material's theoretical density. However, in all consolidation studies of note, the target compaction ratio for the skeleton hardware has been 10:1; thus, these results indicate that this ratio should certainly be achievable, even by crushing/shearing techniques. Of course, melting is clearly better from a volume reduction standpoint, but the cost to the individual utilities would be much higher than for crushing/shearing equipment. However, if rod consolidation is conducted by the federal government at the repository, then melting should be considered. In such a situation, the large scale of the operation might allow the increased volume reduction to offset the additional cost of the melting equipment.

Program Results Verification

Several utilities were contacted in an attempt to obtain information by which the Expert System estimates could be benchmarked. Results were finally gathered from three separate sources which, like the results of the HWES, have varying levels of detail. One source provided detailed information on all NFA hardware types generated at two Combustion Engineering reactors located on a single site. The second source only provided information on control rod assemblies for two Babcock & Wilcox reactors of the same

age, but not operated by the same utility or at the same site. Finally, the third source provided combined data for three Combustion Engineering reactors on the same site. The data was given as total hardware generated at the three reactors, so individual comparisons are not possible in this case. An analysis of this data is presented here.

Table 21 provides a summary of the most detailed verification data, the two Combustion Engineering reactors on the same site. As can be seen from the results, reasonable accuracy was achieved in predicting discharged hardware quantities at Reactor 1, but not at Reactor 2. Table 22, however, shows that the initial information for both reactors was reasonably accurate, so the data which formed the basis for the predictions is acceptable. Further examination of the differences is required.

The predicted values for Reactor 1 almost match the actual values in the majority of cases. In the case of the part length control rods, neutron sources, and guide tube plugs, these components were all permanently discharged

Table 21. A comparison of the predicted hardware discharges versus the actual discharges at two Combustion Engineering reactors on the same site.

Reactor 1 Predicted	Reactor 1 Actual	Hardware Type	Reactor 2 Predicted	Reactor 2 Actual
		Control Rods		
7	8	Part Length	3	0
57	57	Full Length	36	8
131	225	Incore Instrum.	82	112
1	2	Neutron Sources	1	2
-	8	Guide Tube Plugs	-	-

Table 22. A comparison of hardware values provided by the Characteristics Data Base to actual values used by a nuclear utility at two reactor sites. Lifetimes are expressed in units of Effective Full Power Years (EFPY).

	Lifetime		In Use @ Rx 1		In Use @ Rx 2	
	CDB	Actual	CDB	Actual	CDB	Actual
Control Rods						
Full Length	11	8	65	73	83	91
Part Length	-	-	8	0	8	0
Incore Instrum.	3.3	3	45	45	56	56
Neutron Sources	11	3	2	0	2	0

after the first fuel cycle at the reactor, and the use of these items was discontinued. As a result, the Expert System underpredicted the discharged quantities. The predicted value for the full length control rods was exactly correct. The largest error in predictions occurred with the incore instrumentation. The utility personnel who provided the data indicated that there is some debate among the various utilities as to how the incore instrumentation lifetimes should be interpreted. The interpretation followed by many of the utilities provides a lifetime of roughly three fuel cycles, or about four to five years of operation. However, the interpretation used by this utility results in the instrumentation being replaced every two cycles, so the number discharged are 50% higher than might otherwise be expected. If the shorter lifetime of operation had been used for the prediction, the predicted discharges would have been about 196 units, or about 10% off the actual number discharged. Unfortunately, it is not possible to predict in advance which interpretation a given utility will

use; consultation with each utility is needed to accurately predict these values.

In contrast, the values predicted for Reactor 2 are somewhat less accurate. Part length control rods were never used at this reactor, so the number discharged is over-predicted. The two neutron sources, like those at Reactor 1, were permanently discharged and their use was discontinued after the first cycle. The incore instrumentation predictions also differed from the actual values because of the shorter lifetime used by this utility. Using the actual 2-cycle lifetime employed by this utility, the predicted discharges for Reactor 2 would be 123 units, again roughly 10% off from the actual discharges. The largest discrepancy, and the hardest to correct, is in the values for the full length control rods. In this case, the actual discharge rate is roughly a step function, so in the middle of the hardware's lifetime the linear model will show considerable variance from the actual values. At the end of the hardware's lifetime, the predicted and actual values will converge.

The actual data values provided by the second source are compared to the predicted values in Table 23. Since the two reactors are of the same age, the HWES predicted the same number of control rod assemblies would be discharged at each reactor. In the case at Reactor 1, the predicted value is essentially correct. However, at Reactor 2, no Control Rod Assemblies have been discharged; therefore, the

Table 23. A comparison of the predicted hardware discharges versus the actual discharges at two Babcock & Wilcox reactors of the same age.

Reactor 1 Predicted	Reactor 1 Actual	Hardware Type	Reactor 2 Predicted	Reactor 2 Actual
52	51	Control Rods	52	0

predicted value is off by 100%. Unfortunately, the author is unable to gather any additional data from this source, so the reason for this discrepancy is unknown. One possibility is that the operational history of Reactor 2 includes significant periods of downtime, so the reactor's control rods have not yet reached their design lifetime. Alternatively, the control rods at Reactor 1 may have had a defect which required their premature replacement. Again, the author is unable to verify or refute either of these theories.

Since the final source did not provide values for the individual units involved, the values in Table 24 represent total predicted discharges at the three reactors. In this case, the neutron source predictions are correct, while the control rod predictions are 10-15% high. Since the accuracy of the individual predictions cannot be analyzed, this example provides a measure of the general prediction

Table 24. A comparison of the predicted hardware discharges versus the actual discharges at three Combustion Engineering reactors on the same site.

Totals Predicted	Totals Actual	Hardware Type
199	171	Control Rods
6	6	Neutron Sources

capabilities. The data provided by this source indicates that the accuracy of the overall predictions is good.

As a whole, the predictions at five of the seven reactors are reasonably accurate (generally within 10% of the actual values) while the values at the other two reactors are poor. The discrepancies in most of the predicted values are also explainable and relatively easy to correct. For the two reactors where the control rod predictions are inaccurate, the use of a step function may increase the accuracy of the predictions. However, since the accuracy of the predicted values for five out of seven reactors is good, additional data will have to be acquired before this adjustment is justified. In general, the overall performance of the HWES is satisfactory.

Hardware Waste Quantities

Earlier in this chapter, in the "Program Results" section, the results generated by the HWES were presented. Since those results only included those hardware items for which complete information was available, a substantial quantity of information was omitted from those tables. Additionally, the information provided in that section could be used to estimate values for other hardware items which had not been previously estimated. The results of these estimates, as well as the additional values calculated by the HWES, are presented in this section and summarized in Table 25.

Of all the data presented in Table 25, only the values for the Combustion Engineering incore instrumentation remain unchanged. As explained in the "Program Results" section, all nine types of Combustion Engineering incore instrumentation had already been included in the totals, so no further estimating was required for these items. These results were subsequently used to estimate the number of incore instrumentation assemblies discharged for both Babcock & Wilcox and Westinghouse reactors. The estimate was performed on the basis of years of reactor operation. For example, the total operational years of all Combustion Engineering reactors is 156 years, while the total operation

Table 25. Total estimated quantities of NFA hardware discharged as of the year 1990.

		Number of Components	Total Weight (Metric Tons)	Total Volume (Cubic Meters)	Total Heat (Watts)
BWR Fuel Channels		63500	2200	4900	25400
Control Elements	GE	8200	820	1150	164000
	CE	660	25	120	6600
	B&W	490	25	90	4900
	W	2000	90	370	20000
Guide Tube Plugs		--	0.0072	0.019	1.5
Incore Instrum.	B&W	1200	6	0.9	2400
	CE	1300	7	1	2600
	W	4600	25	4	9200
Burnable Poisons		--	0.026	0.18	0.7
Neutron Sources		230	2.8	19.2	23

years for Westinghouse reactors is 548 years. Since the Combustion Engineering reactors discharged roughly 1300 incore instrumentation assemblies in 156 reactor years, it is estimated that the Westinghouse reactors would discharge 1300 x (548/156) = 4600 units. This same procedure was applied to the Babcock & Wilcox reactors, which have a total of 140 reactor years of operation, but not to the General Electric reactors. Without any basis for comparison, it was assumed that the General Electric BWR's were sufficiently different that this means of estimation might not be applicable.

The values for the Babcock & Wilcox and Combustion Engineering control elements and the BWR fuel channels were compiled from the HWES results. The quantities of Westinghouse control elements were estimated from the Babcock & Wilcox control element quantities by the method described above for the incore instrumentation. The weight and volume values for this hardware were then calculated based on Westinghouse information provided in the HWES estimate. The neutron source estimate is based on two sources per operating reactor being discharged after the first fuel cycle. Whether this estimate is reasonable for BWR's is unknown, but due to the size and number of sources involved, even doubling the number of components will not have a significant impact on the FWMS. For guide tube plugs and BPRAs, since no data was available on how many of these items are in use, or had been used, at any reactor, the

author lacked any basis for predicting overall quantities of this waste. Accordingly, quantities data is not provided; instead, the estimated characteristics of a single such item are included for reference purposes and for use in future predictions. Finally, the number of BWR control blades was based on 188 control blades per reactor with a nominal lifetime of 15 years. This data, as well as the estimated weight and volume figures of the control blades, was derived from information presented in the CDB[20] and a report published by E. R. Johnson Associates, Inc.[21] The total operating years for BWR's is 663 years.

The heat load values presented in Table 25 are based on the following values:

BWR Fuel Channel:	0.4 Watts each
PWR Control Rods:	10 Watts each
BWR Control Blades:	20 Watts each
BPRA's:	0.7 Watts each
Incore Instrumentation:	2 Watts each
Neutron Sources:	0.2 Watts each
Thimble Plugs:	1.5 Watts each

With the exception of the BWR control blades, these values are average values derived from the heat load estimates generated by the CDB for these hardware items. These values represent the estimated heat load in a component five years after discharge from the reactor. Since, based on the results presented in the "Hardware Waste Classification" section of chapter 2, the CDB routinely overestimates the control rod exposure, the control rod assembly value was lowered by roughly one-third to compensate. The BWR control blade value is an estimate based on the value presented for

PWR control rods. The higher value is a result of the greater percentage of stainless steel in the control blades, as well as the higher flux experienced by these blades. It should be noted that, because a significant portion of the hardware represented in Table 25 has been discharged for more than 5 years, the actual current heat loads should be lower than estimated.

In most of these components, the dominant heat generator is ^{60}Co which has a half life of roughly five years. Accordingly, the heat rate should drop by a factor of 1000 in 50 years, after which other isotopes become dominant and the overall decay rate slows down. The one notable exception is control rods using Ag-In-Cd as a poison. In these rods, the metastable state of ^{108}Ag is the dominant heat generating isotope. This isotope has a half life of roughly 100 years, so the heat load represented by these control rods is considerably more persistent.

These heat loads can be put into proper context by comparing them with the heat load of individual fuel assemblies. At this time, based on the number and heat load of all currently discharged fuel assemblies, the average heat load of a single PWR fuel assembly is about 2000 watts and that of a single BWR fuel assembly is about 500 watts.[22] For both PWRs and BWRs, the largest NFA hardware heat load comes from the control elements, of which there is about one for every ten assemblies. Thus, control rods contribute about one watt per PWR assembly and control

blades contribute about two watts per BWR assembly. All of the other components combined contribute another one watt per assembly, so that the NFA hardware heat load per PWR assembly is about two watts, or about 0.1% of the assembly's heat load. Similarly for BWRs, NFA hardware provides a total of three watts per BWR assembly, or roughly 0.5% of the assembly's heat load. In either case, the NFA hardware contribution to the heat load is only a small fraction of the assembly's total heat load and would have little, if any, effect on the assembly's disposal if the hardware were disposed of integral to the fuel assemblies.

These results summarize the NFA hardware quantities estimate performed for this work. Examination of Table 25 shows that a considerably greater quantity of data was produced by the HWES than was reflected by Table 19. Additionally, where data on specific hardware items was lacking, the data which was provided was used to help estimate that which was missing. If a serious effort is made by the FWMS to collect the missing data, the accuracy of the HWES can be significantly improved. Nevertheless, the HWES already represents a significant tool for estimating NFA hardware waste quantities and, as such, should prove a useful tool for hardware waste disposal planning.

Notes

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[16]Level5 Rel. 1.2, Information Builders, Inc., Indialantic, FL.

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CHAPTER 5
CONCLUSIONS

As stated in the "Purpose" section of Chapter 1, one of the primary goals of this work is to examine in depth the generation and disposal of NFA and SFD hardware in the United States. Resolution of the contradictory waste classifications provided by different sources was of particular importance. The conclusions reached as a result of the author's analysis are presented in the "Waste Classification" section of this chapter.

The second goal, to develop an Expert System to aid in quantifying and classifying these wastes, was an adjunct to the first goal. Specifically, the Expert System developed for this dissertation and described in Chapter 4 was used as another tool for examining the generation of NFA and SFD hardware wastes. The HWES served as the primary tool for estimating hardware waste quantities. A summary of the hardware quantities estimate from Chapter 4, coupled with the waste classifications derived in Chapter 2, is presented in the section entitled "Waste Quantities."

With the determination of the hardware waste's classification comes a need to specify a method of waste disposal. The waste disposal methods for LLW are well established, but no such policies exist for GTCC wastes.

Three methods for packing and disposing of the hardware wastes are presented in the "Hardware Disposal" section.

Finally, several areas for further work have been identified throughout the course of this dissertation. The majority of these areas center around improving the data used here and/or performing new calculations with the improved data. The remainder examine phenomena which were encountered during this research which are not thoroughly understood. The final section, "Further Work," contains brief descriptions of these potential research topics.

Waste Classification

Resolution of the waste classification controversy for NFA and SFD hardware was probably the most important goal of this work. In an issue teeming with a variety of often contradictory solutions, but without any clear direction, a definitive waste classification system would define the scope of the problem, as well as limit the number of possible solutions. In order to accomplish this goal, an analysis of the work of previous researchers was required. The only source of note concerning NFA hardware is the CDB developed by Oak Ridge National Laboratory. The sources dealing with SFD hardware are only slightly more numerous. In addition to the CDB which also has information on SFD hardware, both Pacific Northwest Laboratories and Rochester Gas & Electric have also performed work on SFD hardware from a number of different reactors.

Examination of these three sources provided three different waste classifications ranging from all hardware being GTCC, as suggested by the CDB, to only hardware constructed of inconel and some stainless steel being GTCC, as concluded by Rochester Gas & Electric. As of April 1991, the PNL report, which fell in between these two extremes, was the most detailed source while the CDB displays a broad range of general information, and the RG&E analysis has not yet been published.

As a part of this work, an extensive analysis of the primary NFA hardware construction materials was performed to determine the time dependent concentrations of zircaloy and nickel which would cause the irradiated material to exceed the Class C limit. The results of this analysis were compared to the concentrations in the material specifications to estimate the permissible irradiation time before the Class C limit would be reached. When coupled with the results of the previous researchers, a general waste classification scheme was developed based on the hardware's material of construction. In general, components constructed of inconel and stainless steel will classify as GTCC waste while those constructed of zircaloy will classify as LLW.

Table 26 illustrates how this waste classification scheme is applied to each hardware category. Examination of this table seems to indicate that the Palisades control blades and the PWR control rod assemblies, both of which are

Table 26. A summary of the classification results broken down by NFA hardware type and materials of construction.

NFA Hardware Type	Materials	Class
BWR Fuel Channels	Zircaloy	LLW
Control Blades (BWR)	Stainless Steel	GTCC
Control Blades (Palisades)	Stainless Steel	LLW
Control Rod Assemblies	Inconel	GTCC
	Stainless Steel	LLW
Thimble Plugs	Stainless Steel	GTCC
Incore Instrumentation	Inconel	GTCC
	Stainless Steel	GTCC
Neutron Sources	Stainless Steel	GTCC
Axial Power Shaping Rods	Inconel	GTCC
Burnable Poisons	Stainless Steel	GTCC
	Zircaloy	LLW

constructed of stainless steel, violate the classification scheme. However, this is not the case. The portions of the control rods which spend their lifetime in the core region are GTCC waste, but since the majority of the control rod assembly is well above the top of the core, when the concentrations in the GTCC portion are averaged over the entire assembly, the assembly classifies as LLW. And as for the BWR fuel channels, while zircaloy does have a burnup limit at 70,000 MWD/MT which a few assemblies may exceed, since the majority of the channels only experience 30-35,000 MWD/MT, those few channels in excess of the limit can easily be averaged so as to classify as LLW.

The conclusion reached as a result of the classification analysis is that the majority of NFA hardware types classify as GTCC waste and thus are the responsibility of the federal government for disposal. Additionally, most of the hardware types which classify as LLW, i.e. BWR fuel

channels, PWR control rod assemblies constructed of stainless steel, and zircaloy-clad burnable poison rods, are likely to be disposed of integral to the fuel assemblies, and thus will also be handled by the FWMS. However, any hardware which classifies as LLW may also be disposed of at the existing LLW disposal sites by either the utilities or the federal government. The effects these classifications have in terms of the relative volumes of the various hardware waste types is shown in the next section.

Waste Quantities

In order to plan for the processing and disposal of wastes, the estimated volume of the waste stream must be determined. The HWES was developed to assist in the approximation of the quantities of NFA hardware which will require disposal in the future. The Expert System approach was used because it would provide a self-documenting system which could be easily updated, thus maintaining its usefulness over time.

Upon the system's completion, NFA hardware quantities could be predicted for any reactor in the United States. However, since the HWES relies on the CDB as its primary data source, the Expert System also reflects the deficiencies of the CDB. In some cases, particularly for BWR's, the data requires significant improvement, so the results are occasionally sketchy. Nevertheless, the estimates produced by the HWES include the majority of the

major hardware categories. Furthermore, the results of these estimates can also be used to approximate values for some of the hardware types with less than complete information, so the majority of the NFA hardware is included within these predictions.

In order to judge the accuracy of the results produced by the HWES, actual NFA hardware discharge data was sought from a variety of sources with limited success. Comparison of this data with the program results indicated that for five out of seven reactors, the Expert System was accurate to within ±10%. At the remaining two reactors, the results were not as good, but this is believed to result from the differences between a linear discharge rate (as modelled) and a step discharge rate (as is believed to occur at these two reactors). As the discharges of the majority of the reactors matched the linear model, a change in the modelling technique is not deemed necessary at this time. Overall, the accuracy of the HWES was judged to be satisfactory.

Table 27 summarizes the results of the HWES estimate of the current (1990) NFA hardware waste inventories. The hardware quantities have been listed in descending order of importance (from a volumetric perspective) and coupled with the results of the waste classification system to provide some indication as to the method of disposal required by each hardware category. As can be seen from the table, two of the largest categories of NFA hardware, namely BWR fuel channels and PWR control rods of stainless steel

Table 27. Summary of NFA hardware waste quantities and waste classifications. The hardware types are listed in descending order of importance from a volumetric standpoint.

	Total Volume (Cubic Meters)	Total Weight (Metric Tons)	Total Heat (Watts)	Class
BWR Fuel Channels	4900	2200	25400	C
Control Blades	1150	820	164000	GTCC
Control (B&W Elements & W)	460	115	24900	C
Burnable Poisons	(each) 0.18	(each) 0.026	(each) 0.7	C OR GTCC
Control (CE) Elements	120	25	6600	GTCC
Incore Instrument.	6	38	14200	GTCC
Guide Tube Plugs	(each) 0.019	(each) 0.0072	(each) 1.5	GTCC
Neutron Sources	19.2	2.8	23	GTCC

construction, classify as LLW. However, these categories are also very likely to be disposed of integral to the spent fuel, thus limiting the utility of the LLW classification. In contrast, the largest NFA hardware category which cannot be disposed of integral to the fuel assemblies, i.e. BWR control blades, classifies as GTCC and thus must be disposed of by the federal government. As a result, the conclusion of this work is that while a few major categories of NFA hardware do qualify for disposal as LLW, in practice, very

little of this hardware is expected to be disposed of as such. Instead, any utility for which the hardware does not represent an immediate storage problem will most likely hold the waste until it is accepted by the federal government.

Hardware Disposal

Current NRC regulations require GTCC waste to be sent to a Federal HLW Repository unless another suitable disposal site is developed. Current DOE plans call for the disposal of NFA hardware integral to the spent fuel assemblies whenever possible. For NFA hardware which cannot be disposed of integral to the spent fuel assemblies, like BWR control blades, both the location and the method of disposal is undecided. Since the NFA and SFD hardware waste streams are related to the spent fuel waste stream, these wastes can be emplaced in a Federal HLW Repository. However, in general, disposal of any waste stream which is not associated with spent nuclear fuel in the Federal HLW Repository is politically unacceptable. One such waste stream is the decommissioning waste stream. The quantities of GTCC waste from decommissioning are expected to be substantial enough to make the development of a separate GTCC waste facility economically feasible. If such a facility were developed, it would provide another potential disposal site for NFA hardware which classifies as GTCC waste. Accordingly, recommendations are made for disposal both at a HLW

repository and at a separate GTCC facility as is most convenient for OCRWM.

Before emplacement in any disposal facility, the hardware should be subjected to a volume reduction process. As was illustrated by the results of the HWES, the volume of hardware for disposal can be reduced by a factor of ten or more if volume reduction is pursued. Since the cost of disposal is related to the volume of the waste, volume reduction would yield significant savings for the FWMS. Volume reduction performed at the reactor site would have the least impact on the FWMS, but would require significant expenditures by the utilities. The approach which makes the least impact on both the FWMS and the utilities is the shipment and disposal of the NFA hardware integral to the spent fuel, but if this is not possible, the most important factor is that the non-integral hardware be compacted before disposal. The volume reduction method used is not important as long as the majority of the void spaces within the hardware are eliminated. While melting would produce the greatest reductions, and thus the greatest savings, crushing and shearing would also produce satisfactory results.

Concerning hardware packaging for disposal, examination of the packaging methods in use for hardware wastes around the world has presented three primary courses of action. The first two involve cutting the hardware and packaging it within an appropriately sized container. The difference between the two methods is whether or not the hardware is

then immobilized by cement grouting. In both of these approaches, the waste package must subsequently be emplaced in a facility for disposal. In the third method, the hardware is cut and deposited into a concrete-lined silo and then immobilized by grouting. The waste is thus treated and disposed of by one procedure.

For the disposal of NFA hardware at the Federal HLW Repository, but not integral to the spent fuel, the only recommended treatment is to cut the hardware and package it loose, without any cement grout. For emplacement in the repository, the ideal package is a consolidation canister or another package of roughly the same dimensions as a fuel assembly. Such a package will require the hardware to be cut into smaller pieces than necessary for a larger canister, but this will allow for tighter, more compact packaging and, by using a container which is the same size as a fuel assembly, the packages can be stored in a conventional fuel pool, transported in a standard spent fuel shipping cask, and otherwise be treated as a spent fuel assembly. This will permit the smoothest integration of these wastes into the FWMS.

For disposal at a separate GTCC waste facility the recommended disposal technique is the use of a concrete-lined silo. This method is derived from a technique used at Morsleben in eastern Germany for the disposal of liquid wastes.[1] After volume reduction, the hardware would be gravity fed into a concrete-lined silo. After a quantity of

hardware has been emplaced, a concrete grout is introduced to immobilize the layer. The procedure is then repeated with each subsequent layer being placed on top of the previous layer. The silo can be of any dimensions, but economy of size dictates that a large silo (possibly 40 feet in diameter and 100 feet deep) which could hold a thousand tons or more of immobilized waste is probably more cost efficient than several small silos. This method of waste emplacement is likely to be the most cost effective of the three methods discussed as the waste goes directly from processing (volume reduction) to disposal without any intervening packaging requirement. The primary drawback of this approach is that the waste form produced is not retrievable and the lack of waste packaging might suffer from poor public perception.

The alternative is to pursue a more standardized waste disposal approach: cut and grout the hardware into canisters. In the United States, one appropriate container might be 55 gallon drums. Since 55 gallon drums are a standard container for LLW disposal, the industry is already experienced in the handling of these drums. Additionally, these drums could be shipped in shielded casks designed for LLW packages, thus requiring no additional cask development. However, a larger container would allow more efficient packaging as less cutting would be required and more hardware could be placed in each container. A cost-benefit analysis would be required to determine the optimum

container size. The primary advantage of this method is that the waste is immobilized within the cement, creating a very durable waste package. The main disadvantage is that this procedure requires additional waste packaging and, thus, would prove more expensive than the silo disposal method described above.

As a side note, these same disposal methods can be applied to SFD hardware from rod consolidation. Rod consolidation demonstrations have already made use of the recommended repository disposal technique, i.e. loose packaging within assembly-sized canisters. If rod consolidation is implemented within the FWMS, the SFD hardware generated could be handled by the same procedures as the NFA hardware and emplaced in the same facility. If a separate GTCC waste facility is developed, the most efficient scenario would call for the spent fuel to be shipped there directly where all consolidation procedures would then be conducted. The SFD hardware waste could then be immediately treated and disposed of while the consolidated spent fuel would then be sent to the repository. This approach would minimize the overall shipping requirements as well as allowing the Federal HLW Repository to deal only with the disposal of spent fuel, instead of the extraneous waste streams. Thus, the development of a dedicated GTCC waste facility would be a versatile, beneficial addition to the Federal Waste Management System.

Further Work

In order to improve the NFA hardware quantity predictions generated by this dissertation, the quality of the available data must be improved. As a result of the utility survey conducted by the DOE, questions about NFA hardware will be added to the survey form completed by the utilities each year. These questions should provide some improvement in the data, but many aspects of the data will probably be neglected, such as hardware lifetimes and material composition. Therefore, an independent survey of the utilities is recommended. As was shown by the difficulties encountered in this dissertation, direct control of the survey must be maintained by the researcher. The survey should also be seen as a method for establishing direct personal contact between the utilities and the researcher. In this way, the researcher should be able to direct the survey procedures so as to ensure that the desired information is provided.

In the elemental analysis presented in Chapter 2, both thermal cross sections and a thermal flux were used to approximate the activation levels experienced by hardware components in the reactor core. In actual reactor operations, the average neutron energy is actually somewhat higher than thermal which lowers the effective cross sections of the isotopes. By using an actual reactor neutron spectrum to determine spectrum-averaged cross sections for the isotopes, the values presented for the

initial allowable concentrations of nickel and niobium can be refined. This analysis could be performed for both PWRs and BWRs, and for different reactor core configurations, to determine how the actual cross sections vary from one reactor to another.

The largest single gap in the NFA hardware information provided by the CDB is the lack of information on General Electric hardware. A thorough examination of the types and characteristics of General Electric NFA hardware would represent a major improvement in the available data. The data could be sought from utility sources or directly from General Electric. This project could also be performed as an adjunct to the utility survey.

A study should be made of the hardware disposal practices of the nuclear utilities. As several utilities are actively engaged in hardware disposal campaigns, these procedures should be analyzed and a determination made as to how much hardware will be disposed of before operation of the FWMS begins. Discarded hardware will reduce the quantities which must be handled by the FWMS, but could represent cost increases as economies of scale are lost. More importantly, as this study has concluded that much of the NFA hardware which has been disposed of in the past is GTCC waste, determination of the total quantities which have been disposed of is important in case remedial action is required.

One of the more unexpected results of the PNL research was the highly variable niobium content found in samples of zircaloy. A detailed analysis of the niobium concentrations in zircaloy could refine the burnup cutoff for zircaloy hardware as defined in this dissertation. Recommendations on how to decrease the levels of niobium in reactor materials would also be beneficial.

The concentration of ^{94}Nb proved to be the determining factor in the classification of zircaloy components as well as a major contributing factor in the classifications of both inconel and stainless steel hardware. If the Class C limit for niobium could be raised, a significant quantity of NFA hardware could be disposed of as LLW. An analysis of ^{94}Nb could be performed to determine if there is any basis for raising this limit.

A detailed financial analysis of the impact of NFA hardware disposal on the FWMS is beyond the scope of this work, but nonetheless important. Thus, a detailed analysis of the three disposal methods presented here is recommended. Additionally, the optimum size for the hardware canisters and the hardware silo should also be determined.

A detailed analysis of a GTCC hardware waste facility could also be performed. The size of the waste facility which would be required to accommodate all NFA hardware waste could be approximated. The analysis should also take into account decommissioning wastes and the effect such a facility would have on the FWMS. For example, would such a

facility be more beneficial to the FWMS before or after the startup of a HLW repository. This analysis could potentially be linked with the cost analysis described above.

Finally, further work can be performed with and on the HWES. With the improved data gathered by the previously mentioned projects, the HWES can be used to perform new estimates on total hardware waste inventories. These calculated inventories should be compared with the survey results to improve the program's accuracy and to suggest refinements to the calculations. Additionally, the Expert System can be corrected to incorporate the utility disposal practices to improve the calculations further. The radiological files included within the CDB also include several decay cases not reflected by the HWES, and these cases could be included to provide a wider range of possible cases. Waste packaging guidelines for GTCC waste currently do not exist. Once such guidelines are developed by the DOE, they can also be included in the HWES. Further improvements on the HWES are also possible and left to other researchers to develop.

In conclusion, most of the goals of this dissertation have been met. A general waste classification scheme was developed which resolved the ambiguities left by previous researchers. The HWES was developed and successfully performs hardware calculations for a wide variety of hardware types and reactors. The accuracy of the Expert

System is felt to be good, and the ongoing efforts to improve on the CDB data will serve to increase the program's accuracy further. Although the utility survey was not performed as expected, the results were still informative, and were particularly important in pointing out the utility hardware disposal plans. Analysis of the hardware disposal practices of foreign countries provided general recommendations for the treatment and disposal of these hardware wastes in the United States. Further work will refine the gathered data and test the feasibility of applying these recommendations to the Federal Waste Management System.

Notes

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APPENDIX A
ESTIMATE OF TOTAL NON-FUEL ASSEMBLY HARDWARE INVENTORIES AS OF 1990

The following is the complete text of the 1990 NFA hardware estimate performed by the Hardware Waste Expert System. Some explanation of the results may be required. All NFA hardware records listed within the CDB are presented for each reactor. Where the available information is incomplete, the code "N/A" has been substituted. For records where "N/A" has been entered in the number column, the information presented in the remaining columns represents the information for a single hardware element. In all other cases, the values are totals for the entire inventory of those components.

The summary totals presented at the end of each reactor listing may not total among themselves. The "Total LECC" heading, for example, includes only those records for which all the calculations could be performed and which classify as Class A, B, or C LLW. Similarly, the "Total GTCC" heading includes only those complete records which classify as GTCC waste. The final "Total," however, includes all records which fell into the previous two categories plus any records for which all information except the Reduced Volume and Classification are available.

The category headings should be self-explanatory, but a

brief explanation of each is presented here. The "Type" heading represents the type of NFA hardware component being listed. The codes are as follows:

B = BWR Fuel Channel	I = Incore Instrumentation
C = Control Elements	P = Burnable Poisons
G = Guide Tube Plugs	S = Neutron Sources

The "Name" heading lists the name of the NFA hardware component as listed by the CDB. The "Number" column indicates the total number of the components which are expected to have been discharged to date. The "Weight" column represents the total weight of the discharged hardware components or the weight of a single component if a "N/A" is present in the "Number" column. "Cu. Vol." stands for the Cubic Volume of the hardware components as discussed in the main text, namely the volume based on the hardware's outer dimensions. Similarly, "Red. Vol." is the Reduced Volume of the hardware or the volume based on the actual volume of the hardware's materials of construction. Both volumes represent the total hardware volume of the components or the volume of a single component if a "N/A" is placed in the "Number" column. Finally, the "Class" column lists the 10CFR61 waste classification of the hardware as calculated by the HWES. The code "> C" indicates waste which classifies as GTCC waste, while the code "<=C" indicates waste which classifies as Class A, B, or C LLW.

Current Waste Inventory: Arkansas 1
1974 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Standard	65	3.8	1.24E+1	4.04E-1	> C
G	Standard	N/A	0.0072	1.91E-2	8.69E-4	> C
P	Gray Ax. Power Shap.	N/A	0.032	1.91E-1	3.96E-3	> C
P	Burnable Poison	N/A	0.026	1.84E-1	4.72E-3	> C
P	Axial Power Shap.	N/A	0.026	1.91E-1	2.90E-3	> C
S	Primary Source	N/A	0.00045	1.74E-1	5.49E-5	> C
S	Regenerative	2	0.042	3.44E-1	2.05E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	3.9	1.28E+1	4.06E-1
Total	3.9	1.28E+1	4.06E-1

Current Waste Inventory: Arkansas 2
1980 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	ANO2 Part Length	5	0.21	9.72E-1	N/A	N/A
C	ANO2 Full Length	45	1.5	8.75E+0	2.81E-1	> C
I	ANO2	92	0.29	5.37E-3	3.96E-2	> C
S	Standard	1	0.0037	8.40E-4	6.39E-4	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	1.8	8.75E+0	3.21E-1
Total	2	9.73E+0	3.21E-1

Current Waste Inventory: Beaver Valley 1
1977 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Beaver Valley 2
1987 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Bellefonte 1
1995 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Bellefonte 2
1995 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Big Rock Point
1962 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Braidwood 1
1988 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Braidwood 2
1988 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Browns Ferry 1
1974 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/4; 80 Mil Thick	2716	85	2.20E+2	N/A	N/A
B	BWR/4,5,100 Mil Thic	2716	1.1E+2	2.20E+2	1.61E+1	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	1.1E+2	2.20E+2	1.61E+1
Total	1.9E+2	4.39E+2	1.61E+1

Current Waste Inventory: Browns Ferry 2
1975 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/4; 80 Mil Thick	2546	80	2.06E+2	N/A	N/A
B	BWR/4,5,100 Mil Thic	2546	99	2.06E+2	1.51E+1	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	99	2.06E+2	1.51E+1
Total	1.8E+2	4.12E+2	1.51E+1

Current Waste Inventory: Browns Ferry 3
1977 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/4; 80 Mil Thick	2207	69	1.79E+2	N/A	N/A
B	BWR/4,5,100 Mil Thic	2207	86	1.79E+2	1.31E+1	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	86	1.79E+2	1.31E+1
Total	1.6E+2	3.57E+2	1.31E+1

Current Waste Inventory: Brunswick 1
1977 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/4; 80 Mil Thick	1617	51	1.31E+2	N/A	N/A
B	BWR/4,5,100 Mil Thic	1617	63	1.31E+2	9.61E+0	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	63	1.31E+2	9.61E+0
Total	1.1E+2	2.62E+2	9.61E+0

Current Waste Inventory: Brunswick 2
1975 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/4; 80 Mil Thick	1866	58	1.51E+2	N/A	N/A
B	BWR/4,5,100 Mil Thic	1866	73	1.51E+2	1.11E+1	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	73	1.51E+2	1.11E+1
Total	1.3E+2	3.02E+2	1.11E+1

Current Waste Inventory: Byron 1
1985 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Byron 2
1987 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Callaway
1985 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Calvert Cliffs 1
1975 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Part Length, Ver. 1	11	0.31	1.91E+0	N/A	N/A
C	Full Length	61	2.1	1.06E+1	4.38E-1	> C
I	Calvert Cliffs	141	0.75	1.09E-1	9.80E-2	> C
S	137 Inch Core	1	0.0049	1.04E-3	7.09E-4	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	2.9	1.07E+1	5.36E-1
Total	3.2	1.26E+1	5.36E-1

Current Waste Inventory: Calvert Cliffs 2
1977 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Part Length, Ver. 1	9	0.26	1.56E+0	N/A	N/A
C	Full Length	53	1.8	9.21E+0	3.80E-1	> C
I	Calvert Cliffs	122	0.65	9.46E-2	8.48E-2	> C
S	137 Inch Core	1	0.0049	1.04E-3	7.09E-4	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	2.5	9.31E+0	4.66E-1
Total	2.8	1.09E+1	4.66E-1

Current Waste Inventory: Catawba 1
1985 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Catawba 2
1986 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Clinton
1987 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/6; 120 Mil Thick	296	14	2.42E+1	N/A	N/A

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	14	2.42E+1	0.00E+0

Current Waste Inventory: Comanche Peak 1
1989 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Comanche Peak 2
1992 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Cook 1
1975 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Standard	N/A	0.075	1.83E-1	N/A	N/A
G	Standard	N/A	0.0049	1.19E-2	6.12E-4	> C
P	WABA (8-Rod)	N/A	0.01	1.79E-1	1.71E-3	> C
P	WABA (20-Rod)	N/A	0.019	1.79E-1	3.35E-3	> C
P	Short WABA (4-Rod)	N/A	0.0075	1.71E-1	1.09E-3	> C
P	Short WABA (12-Rod)	N/A	0.013	1.71E-1	2.05E-3	> C
P	BPA (4-Rod)	N/A	0.0093	1.82E-1	1.59E-3	> C
P	BPA (10-Rod)	N/A	0.015	1.82E-1	2.99E-3	> C
P	BPA (20-Rod)	N/A	0.024	1.82E-1	5.31E-3	> C
S	Primary, Version 1	N/A	0.024	1.84E-1	3.80E-3	> C
S	Primary, Version 2	N/A	0.024	1.84E-1	3.80E-3	> C
S	Primary, Version 3	N/A	0.015	1.82E-1	3.42E-3	> C
S	Secondary, 116 Inch	N/A	0.013	1.35E-1	8.17E-4	> C
S	Secondary, 143 Inch	N/A	0.011	1.67E-1	1.16E-3	> C
S	Secondary, 157 Inch	N/A	0.0086	1.82E-1	8.18E-4	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Cook 2
1978 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Cooper Station
1974 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/4; 80 Mil Thick	1948	61	1.58E+2	N/A	N/A
B	BWR/4,5,100 Mil Thic	1948	76	1.58E+2	1.16E+1	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	76	1.58E+2	1.16E+1
Total	1.4E+2	3.15E+2	1.16E+1

Current Waste Inventory: Crystal River 3
1977 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Standard	52	3.1	9.93E+0	N/A	N/A
G	Standard	N/A	0.0072	1.91E-2	8.69E-4	> C
P	Gray Ax. Power Shap.	N/A	0.032	1.91E-1	3.96E-3	> C
P	Burnable Poison	N/A	0.026	1.84E-1	4.72E-3	> C
P	Axial Power Shap.	N/A	0.026	1.91E-1	2.90E-3	> C
S	Primary Source	N/A	0.00045	1.74E-1	5.49E-5	> C
S	Regenerative	1	0.021	1.72E-1	1.03E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0.021	1.72E-1	1.03E-3
Total	3.1	1.01E+1	1.03E-3

Current Waste Inventory: Davis-Besse
1977 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Standard	52	3.1	9.93E+0	N/A	N/A
G	Standard	N/A	0.0072	1.91E-2	8.69E-4	> C
P	Gray Ax. Power Shap.	N/A	0.032	1.91E-1	3.96E-3	> C
P	Burnable Poison	N/A	0.026	1.84E-1	4.72E-3	> C
P	Axial Power Shap.	N/A	0.026	1.91E-1	2.90E-3	> C
S	Primary Source	N/A	0.00045	1.74E-1	5.49E-5	> C
S	Regenerative	1	0.021	1.72E-1	1.03E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0.021	1.72E-1	1.03E-3
Total	3.1	1.01E+1	1.03E-3

Current Waste Inventory: Diablo Canyon 1
1985 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Diablo Canyon 2
1986 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Dresden 1
1960 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	Dresden, 60 Mil	3253	44	1.24E+2	N/A	N/A

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	44	1.24E+2	0.00E+0

Current Waste Inventory: Dresden 2
1970 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/2,3;80 Mil Thick	3217	98	2.53E+2	N/A	N/A

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	98	2.53E+2	0.00E+0

Current Waste Inventory: Dresden 3
1971 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/2,3;80 Mil Thick	3056	93	2.40E+2	N/A	N/A

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	93	2.40E+2	0.00E+0

Current Waste Inventory: Duane Arnold
1975 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/4; 80 Mil Thick	1226	38	9.92E+1	N/A	N/A
B	BWR/4,5,100 Mil Thic	1226	48	9.92E+1	7.29E+0	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	48	9.92E+1	7.29E+0
Total	86	1.98E+2	7.29E+0

Current Waste Inventory: Enrico Fermi 2
1988 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/4; 80 Mil Thick	339	11	2.74E+1	N/A	N/A
B	BWR/4,5,100 Mil Thic	339	13	2.74E+1	2.02E+0	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	13	2.74E+1	2.02E+0
Total	24	5.48E+1	2.02E+0

Current Waste Inventory: Farley 1
1977 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Farley 2
1981 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Fitzpatrick
1975 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/4; 80 Mil Thick	1866	58	1.51E+2	N/A	N/A
B	BWR/4,5,100 Mil Thic	1866	73	1.51E+2	1.11E+1	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	73	1.51E+2	1.11E+1
Total	1.3E+2	3.02E+2	1.11E+1

Current Waste Inventory: Fort Calhoun
1973 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Part Length	4	0.11	6.54E-1	N/A	N/A
C	Full Length	48	1.4	7.84E+0	3.24E-1	> C
I	Ft. Calhoun	99	0.52	7.31E-2	6.82E-2	> C
S	128 Inch Core	2	0.0096	1.97E-3	1.09E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	2	7.92E+0	3.93E-1
Total	2.1	8.57E+0	3.93E-1

Current Waste Inventory: Ginna
1970 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Standard	N/A	0.058	1.56E-1	N/A	N/A
C	Short, Ver. 1	N/A	0.058	1.55E-1	5.30E-3	> C
C	Short, Ver. 2	N/A	0.049	1.32E-1	5.27E-3	> C
G	Water Displacement	N/A	0.0093	1.54E-1	1.14E-3	> C
G	Standard	N/A	0.0043	1.19E-2	5.38E-4	> C
P	(4-Rod)	N/A	0.0077	1.54E-1	1.46E-3	> C
P	(12-Rod)	N/A	0.015	1.54E-1	3.31E-3	> C
P	BPA (16-Rod)	N/A	0.018	1.54E-1	4.22E-3	> C
P	WABA (4-Rod)	N/A	0.0071	1.52E-1	1.07E-3	> C
P	WABA (12-Rod)	N/A	0.013	1.52E-1	2.17E-3	> C
P	WABA (16-Rod)	N/A	0.016	1.52E-1	2.73E-3	> C
S	Primary, Version 1	N/A	0.022	1.24E-1	3.77E-3	> C
S	Primary, Version 2	N/A	0.022	1.56E-1	3.78E-3	> C
S	Primary, Version 3	N/A	0.022	1.56E-1	3.78E-3	> C
S	Secondary, 116 Inch	N/A	0.01	1.15E-1	9.53E-4	> C
S	Secondary, 137 Inch	N/A	0.011	1.36E-1	1.00E-3	> C
S	Secondary, 143 Inch	N/A	0.01	1.41E-1	1.04E-3	> C
S	Secondary, 157 Inch	N/A	0.013	1.55E-1	1.04E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Grand Gulf 1
1985 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/6; 120 Mil Thick	653	31	5.33E+1	N/A	N/A

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	31	5.33E+1	0.00E+0

Current Waste Inventory: Grand Gulf 2
1995 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/6; 120 Mil Thick	0	0	0.00E+0	N/A	N/A

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Haddam Neck
1968 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Standard	N/A	0.075	1.84E-1	N/A	N/A
G	Standard	N/A	0.0049	1.20E-2	6.12E-4	> C
P	WABA (8-Rod)	N/A	0.01	1.81E-1	1.71E-3	> C
P	WABA (20-Rod)	N/A	0.019	1.81E-1	3.35E-3	> C
P	Short WABA (4-Rod)	N/A	0.0075	1.72E-1	1.09E-3	> C
P	Short WABA (12-Rod)	N/A	0.013	1.72E-1	2.05E-3	> C
P	BPA (4-Rod)	N/A	0.0093	1.83E-1	1.59E-3	> C
P	BPA (10-Rod)	N/A	0.015	1.83E-1	2.99E-3	> C
P	BPA (20-Rod)	N/A	0.024	1.83E-1	5.31E-3	> C
S	Primary, Version 1	N/A	0.024	1.86E-1	3.80E-3	> C
S	Primary, Version 2	N/A	0.024	1.86E-1	3.80E-3	> C
S	Primary, Version 3	N/A	0.015	1.83E-1	3.42E-3	> C
S	Secondary, 116 Inch	N/A	0.013	1.36E-1	8.17E-4	> C
S	Secondary, 143 Inch	N/A	0.011	1.68E-1	1.16E-3	> C
S	Secondary, 157 Inch	N/A	0.0086	1.83E-1	8.18E-4	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Harris
1987 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Hatch 1
1975 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/4; 80 Mil Thick	1866	58	1.51E+2	N/A	N/A
B	BWR/4,5,100 Mil Thic	1866	73	1.51E+2	1.11E+1	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	73	1.51E+2	1.11E+1
Total	1.3E+2	3.02E+2	1.11E+1

Current Waste Inventory: Hatch 2
1979 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/4; 80 Mil Thick	1368	43	1.11E+2	N/A	N/A
B	BWR/4,5,100 Mil Thic	1368	53	1.11E+2	8.13E+0	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	53	1.11E+2	8.13E+0
Total	96	2.21E+2	8.13E+0

Current Waste Inventory: Hope Creek
1987 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/4; 80 Mil Thick	509	16	4.12E+1	N/A	N/A
B	BWR/4,5,100 Mil Thic	509	20	4.12E+1	3.03E+0	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	20	4.12E+1	3.03E+0
Total	36	8.23E+1	3.03E+0

Current Waste Inventory: Humboldt Bay
1963 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	Humboldt Bay	1032	11	3.26E+1	N/A	N/A

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	11	3.26E+1	0.00E+0

Current Waste Inventory: Indian Point 1
1962 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Indian Point 2
1974 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Standard	N/A	0.075	1.83E-1	N/A	N/A
G	Standard	N/A	0.0049	1.19E-2	6.12E-4	> C
P	WABA (8-Rod)	N/A	0.01	1.79E-1	1.71E-3	> C
P	WABA (20-Rod)	N/A	0.019	1.79E-1	3.35E-3	> C
P	Short WABA (4-Rod)	N/A	0.0075	1.71E-1	1.09E-3	> C
P	Short WABA (12-Rod)	N/A	0.013	1.71E-1	2.05E-3	> C
P	BPA (4-Rod)	N/A	0.0093	1.82E-1	1.59E-3	> C
P	BPA (10-Rod)	N/A	0.015	1.82E-1	2.99E-3	> C
P	BPA (20-Rod)	N/A	0.024	1.82E-1	5.31E-3	> C
S	Primary, Version 1	N/A	0.024	1.84E-1	3.80E-3	> C
S	Primary, Version 2	N/A	0.024	1.84E-1	3.80E-3	> C
S	Primary, Version 3	N/A	0.015	1.82E-1	3.42E-3	> C
S	Secondary, 116 Inch	N/A	0.013	1.35E-1	8.17E-4	> C
S	Secondary, 143 Inch	N/A	0.011	1.67E-1	1.16E-3	> C
S	Secondary, 157 Inch	N/A	0.0086	1.82E-1	8.18E-4	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Indian Point 3
1976 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Standard	N/A	0.075	1.83E-1	N/A	N/A
G	Standard	N/A	0.0049	1.19E-2	6.12E-4	> C
P	WABA (8-Rod)	N/A	0.01	1.79E-1	1.71E-3	> C
P	WABA (20-Rod)	N/A	0.019	1.79E-1	3.35E-3	> C
P	Short WABA (4-Rod)	N/A	0.0075	1.71E-1	1.09E-3	> C
P	Short WABA (12-Rod)	N/A	0.013	1.71E-1	2.05E-3	> C
P	BPA (4-Rod)	N/A	0.0093	1.82E-1	1.59E-3	> C
P	BPA (10-Rod)	N/A	0.015	1.82E-1	2.99E-3	> C
P	BPA (20-Rod)	N/A	0.024	1.82E-1	5.31E-3	> C
S	Primary, Version 1	N/A	0.024	1.84E-1	3.80E-3	> C
S	Primary, Version 2	N/A	0.024	1.84E-1	3.80E-3	> C
S	Primary, Version 3	N/A	0.015	1.82E-1	3.42E-3	> C
S	Secondary, 116 Inch	N/A	0.013	1.35E-1	8.17E-4	> C
S	Secondary, 143 Inch	N/A	0.011	1.67E-1	1.16E-3	> C
S	Secondary, 157 Inch	N/A	0.0086	1.82E-1	8.18E-4	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Kewaunee
1974 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Standard	N/A	0.058	1.56E-1	N/A	N/A
C	Short, Ver. 1	N/A	0.058	1.55E-1	5.30E-3	> C
C	Short, Ver. 2	N/A	0.049	1.32E-1	5.27E-3	> C
G	Water Displacement	N/A	0.0093	1.54E-1	1.14E-3	> C
G	Standard	N/A	0.0043	1.19E-2	5.38E-4	> C
P	(4-Rod)	N/A	0.0077	1.54E-1	1.46E-3	> C
P	(12-Rod)	N/A	0.015	1.54E-1	3.31E-3	> C
P	BPA (16-Rod)	N/A	0.018	1.54E-1	4.22E-3	> C
P	WABA (4-Rod)	N/A	0.0071	1.52E-1	1.07E-3	> C
P	WABA (12-Rod)	N/A	0.013	1.52E-1	2.17E-3	> C
P	WABA (16-Rod)	N/A	0.016	1.52E-1	2.73E-3	> C
S	Primary, Version 1	N/A	0.022	1.24E-1	3.77E-3	> C
S	Primary, Version 2	N/A	0.022	1.56E-1	3.78E-3	> C
S	Primary, Version 3	N/A	0.022	1.56E-1	3.78E-3	> C
S	Secondary, 116 Inch	N/A	0.01	1.15E-1	9.53E-4	> C
S	Secondary, 137 Inch	N/A	0.011	1.36E-1	1.00E-3	> C
S	Secondary, 143 Inch	N/A	0.01	1.41E-1	1.04E-3	> C
S	Secondary, 157 Inch	N/A	0.013	1.55E-1	1.04E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: LaCrosse
1969 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: LaSalle 1
1982 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/4,5,100 Mil Thic	1358	53	1.10E+2	N/A	N/A

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	53	1.10E+2	0.00E+0

Current Waste Inventory: LaSalle 2
1984 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/4,5,100 Mil Thic	1018	40	8.23E+1	N/A	N/A

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	40	8.23E+1	0.00E+0

Current Waste Inventory: Limerick 1
1986 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/4; 80 Mil Thick	679	21	5.49E+1	N/A	N/A
B	BWR/4,5,100 Mil Thic	679	26	5.49E+1	4.04E+0	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	26	5.49E+1	4.04E+0
Total	48	1.10E+2	4.04E+0

Current Waste Inventory: Limerick 2
1990 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/4; 80 Mil Thick	0	0	0.00E+0	N/A	N/A
B	BWR/4,5,100 Mil Thic	0	0	0.00E+0	0.00E+0	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Maine Yankee
1972 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Part Length, Ver. 3	13	0.62	2.26E+0	N/A	N/A
C	Full Length	73	2.5	1.27E+1	5.24E-1	> C
S	137 Inch Core	2	0.0099	2.09E-3	1.42E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	2.6	1.27E+1	5.25E-1
Total	3.2	1.50E+1	5.25E-1

Current Waste Inventory: McGuire 1
1981 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: McGuire 2
1984 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Millstone 1

1970 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/2,3;80 Mil Thick	2577	78	2.02E+2	N/A	N/A

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	78	2.02E+2	0.00E+0

Current Waste Inventory: Millstone 2

1975 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Part Length, Ver. 2	7	0.26	1.22E+0	N/A	N/A
C	Full Length	61	2.1	1.06E+1	4.38E-1	> C
I	Millstone 2	141	0.81	1.01E-1	1.07E-1	> C
S	137 Inch Core	1	0.0049	1.04E-3	7.09E-4	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	2.9	1.07E+1	5.45E-1
Total	3.2	1.19E+1	5.45E-1

Current Waste Inventory: Millstone 3

1986 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Monticello
1971 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/2,3;80 Mil Thick	2043	62	1.61E+2	N/A	N/A

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	62	1.61E+2	0.00E+0

Current Waste Inventory: Nine Mile Point 1
1969 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/2,3;80 Mil Thick	2482	75	1.95E+2	N/A	N/A

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	75	1.95E+2	0.00E+0

Current Waste Inventory: Nine Mile Point 2
1988 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/4,5,100 Mil Thic	339	13	2.74E+1	N/A	N/A

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	13	2.74E+1	0.00E+0

Current Waste Inventory: North Anna 1
1978 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: North Anna 2
1980 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Oconee 1
1973 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Standard	69	4.1	1.32E+1	N/A	N/A
G	Standard	N/A	0.0072	1.91E-2	8.69E-4	> C
P	Gray Ax. Power Shap.	N/A	0.032	1.91E-1	3.96E-3	> C
P	Burnable Poison	N/A	0.026	1.84E-1	4.72E-3	> C
P	Axial Power Shap.	N/A	0.026	1.91E-1	2.90E-3	> C
S	Primary Source	N/A	0.00045	1.74E-1	5.49E-5	> C
S	Regenerative	2	0.042	3.44E-1	2.05E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0.042	3.44E-1	2.05E-3
Total	4.1	1.35E+1	2.05E-3

Current Waste Inventory: Oconee 2
1974 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Standard	65	3.8	1.24E+1	N/A	N/A
G	Standard	N/A	0.0072	1.91E-2	8.69E-4	> C
P	Gray Ax. Power Shap.	N/A	0.032	1.91E-1	3.96E-3	> C
P	Burnable Poison	N/A	0.026	1.84E-1	4.72E-3	> C
P	Axial Power Shap.	N/A	0.026	1.91E-1	2.90E-3	> C
S	Primary Source	N/A	0.00045	1.74E-1	5.49E-5	> C
S	Regenerative	2	0.042	3.44E-1	2.05E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0.042	3.44E-1	2.05E-3
Total	3.9	1.28E+1	2.05E-3

Current Waste Inventory: Oconee 3
1974 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Standard	65	3.8	1.24E+1	N/A	N/A
G	Standard	N/A	0.0072	1.91E-2	8.69E-4	> C
P	Gray Ax. Power Shap.	N/A	0.032	1.91E-1	3.96E-3	> C
P	Burnable Poison	N/A	0.026	1.84E-1	4.72E-3	> C
P	Axial Power Shap.	N/A	0.026	1.91E-1	2.90E-3	> C
S	Primary Source	N/A	0.00045	1.74E-1	5.49E-5	> C
S	Regenerative	2	0.042	3.44E-1	2.05E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0.042	3.44E-1	2.05E-3
Total	3.9	1.28E+1	2.05E-3

Current Waste Inventory: Oyster Creek
1969 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/2,3;80 Mil Thick	2613	79	2.05E+2	N/A	N/A

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	79	2.05E+2	0.00E+0

Current Waste Inventory: Palisades
1971 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Cruciform Blade	28	2.7	4.72E+0	N/A	N/A
I	Palisades	171	0.72	1.20E-1	9.68E-2	> C
S	Sustaining	2	0.0041	3.48E-4	5.81E-4	> C
S	Start-up	2	0.0041	3.48E-4	5.86E-4	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0.73	1.20E-1	9.80E-2
Total	3.4	4.84E+0	9.80E-2

Current Waste Inventory: Palo Verde 1
1986 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	SYS80 4 Rod Part Len	3	0.13	8.16E-1	N/A	N/A
C	SYS80 12Rod Full Len	12	1	3.26E+0	2.00E-1	> C
I	System 80	51	0.79	1.85E-1	1.03E-1	> C
S	Standard	0	0	0.00E+0	0.00E+0	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	1.8	3.45E+0	3.03E-1
Total	2	4.27E+0	3.03E-1

Current Waste Inventory: Palo Verde 2
1986 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	SYS80 4 Rod Part Len	3	0.13	8.16E-1	N/A	N/A
C	SYS80 12Rod Full Len	12	1	3.26E+0	2.00E-1	> C
I	System 80	51	0.79	1.85E-1	1.03E-1	> C
S	Standard	0	0	0.00E+0	0.00E+0	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	1.8	3.45E+0	3.03E-1
Total	2	4.27E+0	3.03E-1

Current Waste Inventory: Palo Verde 3
1988 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	SYS80 4 Rod Part Len	1	0.043	2.72E-1	N/A	N/A
C	SYS80 12Rod Full Len	6	0.52	1.63E+0	9.99E-2	> C
I	System 80	25	0.39	9.07E-2	5.05E-2	> C
S	Standard	0	0	0.00E+0	0.00E+0	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0.91	1.72E+0	1.50E-1
Total	0.96	1.99E+0	1.50E-1

Current Waste Inventory: Peach Bottom 2
1974 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/4; 80 Mil Thick	2716	85	2.20E+2	N/A	N/A
B	BWR/4,5,100 Mil Thic	2702	1.1E+2	2.19E+2	1.61E+1	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	1.1E+2	2.19E+2	1.61E+1
Total	1.9E+2	4.38E+2	1.61E+1

Current Waste Inventory: Peach Bottom 3
1974 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/4; 80 Mil Thick	2716	85	2.20E+2	N/A	N/A
B	BWR/4,5,100 Mil Thic	2702	1.1E+2	2.19E+2	1.61E+1	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	1.1E+2	2.19E+2	1.61E+1
Total	1.9E+2	4.38E+2	1.61E+1

Current Waste Inventory: Perry 1
1987 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/6; 120 Mil Thick	392	18	3.20E+1	N/A	N/A

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	18	3.20E+1	0.00E+0

Current Waste Inventory: Perry 2
1995 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/6; 120 Mil Thick	0	0	0.00E+0	N/A	N/A

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Pilgrim
1972 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/3, Long 80 Mil	2320	74	1.92E+2	N/A	N/A

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	74	1.92E+2	0.00E+0

Current Waste Inventory: Point Beach 1
1970 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Standard	N/A	0.058	1.56E-1	N/A	N/A
C	Short, Ver. 1	N/A	0.058	1.55E-1	5.30E-3	> C
C	Short, Ver. 2	N/A	0.049	1.32E-1	5.27E-3	> C
G	Water Displacement	N/A	0.0093	1.54E-1	1.14E-3	> C
G	Standard	N/A	0.0043	1.19E-2	5.38E-4	> C
P	(4-Rod)	N/A	0.0077	1.54E-1	1.46E-3	> C
P	(12-Rod)	N/A	0.015	1.54E-1	3.31E-3	> C
P	BPA (16-Rod)	N/A	0.018	1.54E-1	4.22E-3	> C
P	WABA (4-Rod)	N/A	0.0071	1.52E-1	1.07E-3	> C
P	WABA (12-Rod)	N/A	0.013	1.52E-1	2.17E-3	> C
P	WABA (16-Rod)	N/A	0.016	1.52E-1	2.73E-3	> C
S	Primary, Version 1	N/A	0.022	1.24E-1	3.77E-3	> C
S	Primary, Version 2	N/A	0.022	1.56E-1	3.78E-3	> C
S	Primary, Version 3	N/A	0.022	1.56E-1	3.78E-3	> C
S	Secondary, 116 Inch	N/A	0.01	1.15E-1	9.53E-4	> C
S	Secondary, 137 Inch	N/A	0.011	1.36E-1	1.00E-3	> C
S	Secondary, 143 Inch	N/A	0.01	1.41E-1	1.04E-3	> C
S	Secondary, 157 Inch	N/A	0.013	1.55E-1	1.04E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Point Beach 2
1972 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Standard	N/A	0.058	1.56E-1	N/A	N/A
C	Short, Ver. 1	N/A	0.058	1.55E-1	5.30E-3	> C
C	Short, Ver. 2	N/A	0.049	1.32E-1	5.27E-3	> C
G	Water Displacement	N/A	0.0093	1.54E-1	1.14E-3	> C
G	Standard	N/A	0.0043	1.19E-2	5.38E-4	> C
P	(4-Rod)	N/A	0.0077	1.54E-1	1.46E-3	> C
P	(12-Rod)	N/A	0.015	1.54E-1	3.31E-3	> C
P	BPA (16-Rod)	N/A	0.018	1.54E-1	4.22E-3	> C
P	WABA (4-Rod)	N/A	0.0071	1.52E-1	1.07E-3	> C
P	WABA (12-Rod)	N/A	0.013	1.52E-1	2.17E-3	> C
P	WABA (16-Rod)	N/A	0.016	1.52E-1	2.73E-3	> C
S	Primary, Version 1	N/A	0.022	1.24E-1	3.77E-3	> C
S	Primary, Version 2	N/A	0.022	1.56E-1	3.78E-3	> C
S	Primary, Version 3	N/A	0.022	1.56E-1	3.78E-3	> C
S	Secondary, 116 Inch	N/A	0.01	1.15E-1	9.53E-4	> C
S	Secondary, 137 Inch	N/A	0.011	1.36E-1	1.00E-3	> C
S	Secondary, 143 Inch	N/A	0.01	1.41E-1	1.04E-3	> C
S	Secondary, 157 Inch	N/A	0.013	1.55E-1	1.04E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Prairie Island 1
1973 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Standard	N/A	0.058	1.56E-1	N/A	N/A
C	Short, Ver. 1	N/A	0.058	1.55E-1	5.30E-3	> C
C	Short, Ver. 2	N/A	0.049	1.32E-1	5.27E-3	> C
G	Water Displacement	N/A	0.0093	1.54E-1	1.14E-3	> C
G	Standard	N/A	0.0043	1.19E-2	5.38E-4	> C
P	(4-Rod)	N/A	0.0077	1.54E-1	1.46E-3	> C
P	(12-Rod)	N/A	0.015	1.54E-1	3.31E-3	> C
P	BPA (16-Rod)	N/A	0.018	1.54E-1	4.22E-3	> C
P	WABA (4-Rod)	N/A	0.0071	1.52E-1	1.07E-3	> C
P	WABA (12-Rod)	N/A	0.013	1.52E-1	2.17E-3	> C
P	WABA (16-Rod)	N/A	0.016	1.52E-1	2.73E-3	> C
S	Primary, Version 1	N/A	0.022	1.24E-1	3.77E-3	> C
S	Primary, Version 2	N/A	0.022	1.56E-1	3.78E-3	> C
S	Primary, Version 3	N/A	0.022	1.56E-1	3.78E-3	> C
S	Secondary, 116 Inch	N/A	0.01	1.15E-1	9.53E-4	> C
S	Secondary, 137 Inch	N/A	0.011	1.36E-1	1.00E-3	> C
S	Secondary, 143 Inch	N/A	0.01	1.41E-1	1.04E-3	> C
S	Secondary, 157 Inch	N/A	0.013	1.55E-1	1.04E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Prairie Island 2
1974 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Standard	N/A	0.058	1.56E-1	N/A	N/A
C	Short, Ver. 1	N/A	0.058	1.55E-1	5.30E-3	> C
C	Short, Ver. 2	N/A	0.049	1.32E-1	5.27E-3	> C
G	Water Displacement	N/A	0.0093	1.54E-1	1.14E-3	> C
G	Standard	N/A	0.0043	1.19E-2	5.38E-4	> C
P	(4-Rod)	N/A	0.0077	1.54E-1	1.46E-3	> C
P	(12-Rod)	N/A	0.015	1.54E-1	3.31E-3	> C
P	BPA (16-Rod)	N/A	0.018	1.54E-1	4.22E-3	> C
P	WABA (4-Rod)	N/A	0.0071	1.52E-1	1.07E-3	> C
P	WABA (12-Rod)	N/A	0.013	1.52E-1	2.17E-3	> C
P	WABA (16-Rod)	N/A	0.016	1.52E-1	2.73E-3	> C
S	Primary, Version 1	N/A	0.022	1.24E-1	3.77E-3	> C
S	Primary, Version 2	N/A	0.022	1.56E-1	3.78E-3	> C
S	Primary, Version 3	N/A	0.022	1.56E-1	3.78E-3	> C
S	Secondary, 116 Inch	N/A	0.01	1.15E-1	9.53E-4	> C
S	Secondary, 137 Inch	N/A	0.011	1.36E-1	1.00E-3	> C
S	Secondary, 143 Inch	N/A	0.01	1.41E-1	1.04E-3	> C
S	Secondary, 157 Inch	N/A	0.013	1.55E-1	1.04E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Quad Cities 1
1972 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/2,3;80 Mil Thick	2896	88	2.28E+2	N/A	N/A

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	88	2.28E+2	0.00E+0

Current Waste Inventory: Quad Cities 2
1972 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/2,3;80 Mil Thick	2896	88	2.28E+2	N/A	N/A

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	88	2.28E+2	0.00E+0

Current Waste Inventory: Rancho Seco
1975 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Standard	53	3.1	1.01E+1	N/A	N/A
G	Standard	N/A	0.0072	1.91E-2	8.69E-4	> C
P	Gray Ax. Power Shap.	N/A	0.032	1.91E-1	3.96E-3	> C
P	Burnable Poison	N/A	0.026	1.84E-1	4.72E-3	> C
P	Axial Power Shap.	N/A	0.026	1.91E-1	2.90E-3	> C
S	Primary Source	N/A	0.00045	1.74E-1	5.49E-5	> C
S	Regenerative	2	0.042	3.44E-1	2.05E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0.042	3.44E-1	2.05E-3
Total	3.2	1.05E+1	2.05E-3

Current Waste Inventory: River Bend 1
1986 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/6; 120 Mil Thick	394	19	3.22E+1	N/A	N/A

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	19	3.22E+1	0.00E+0

Current Waste Inventory: Robinson 2
1971 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Standard	N/A	0.075	1.83E-1	N/A	N/A
G	Standard	N/A	0.0049	1.19E-2	6.12E-4	> C
P	WABA (8-Rod)	N/A	0.01	1.79E-1	1.71E-3	> C
P	WABA (20-Rod)	N/A	0.019	1.79E-1	3.35E-3	> C
P	Short WABA (4-Rod)	N/A	0.0075	1.71E-1	1.09E-3	> C
P	Short WABA (12-Rod)	N/A	0.013	1.71E-1	2.05E-3	> C
P	BPA (4-Rod)	N/A	0.0093	1.82E-1	1.59E-3	> C
P	BPA (10-Rod)	N/A	0.015	1.82E-1	2.99E-3	> C
P	BPA (20-Rod)	N/A	0.024	1.82E-1	5.31E-3	> C
S	Primary, Version 1	N/A	0.024	1.84E-1	3.80E-3	> C
S	Primary, Version 2	N/A	0.024	1.84E-1	3.80E-3	> C
S	Primary, Version 3	N/A	0.015	1.82E-1	3.42E-3	> C
S	Secondary, 116 Inch	N/A	0.013	1.35E-1	8.17E-4	> C
S	Secondary, 143 Inch	N/A	0.011	1.67E-1	1.16E-3	> C
S	Secondary, 157 Inch	N/A	0.0086	1.82E-1	8.18E-4	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Salem 1
1977 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Salem 2
1981 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: San Onofre 1
1968 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Standard	N/A	0.058	1.56E-1	N/A	N/A
C	Short, Ver. 1	N/A	0.058	1.55E-1	5.30E-3	> C
C	Short, Ver. 2	N/A	0.049	1.32E-1	5.27E-3	> C
G	Water Displacement	N/A	0.0093	1.54E-1	1.14E-3	> C
G	Standard	N/A	0.0043	1.19E-2	5.38E-4	> C
P	(4-Rod)	N/A	0.0077	1.54E-1	1.46E-3	> C
P	(12-Rod)	N/A	0.015	1.54E-1	3.31E-3	> C
P	BPA (16-Rod)	N/A	0.018	1.54E-1	4.22E-3	> C
P	WABA (4-Rod)	N/A	0.0071	1.52E-1	1.07E-3	> C
P	WABA (12-Rod)	N/A	0.013	1.52E-1	2.17E-3	> C
P	WABA (16-Rod)	N/A	0.016	1.52E-1	2.73E-3	> C
S	Primary, Version 1	N/A	0.022	1.24E-1	3.77E-3	> C
S	Secondary, 116 Inch	N/A	0.01	1.15E-1	9.53E-4	> C
S	Secondary, 137 Inch	N/A	0.011	1.36E-1	1.00E-3	> C
S	Secondary, 143 Inch	N/A	0.01	1.41E-1	1.04E-3	> C
S	Secondary, 157 Inch	N/A	0.013	1.55E-1	1.04E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: San Onofre 2
1983 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	San Onofre Part Len	3	0.13	5.84E-1	N/A	N/A
C	San Onofre Full Len	36	1.2	7.01E+0	2.25E-1	> C
I	San Onofre	82	0.24	4.78E-3	3.34E-2	> C
S	Standard	1	0.0037	8.40E-4	6.39E-4	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	1.4	7.01E+0	2.59E-1
Total	1.5	7.60E+0	2.59E-1

Current Waste Inventory: San Onofre 3
1984 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	San Onofre Part Len	3	0.13	5.84E-1	N/A	N/A
C	San Onofre Full Len	31	1	6.03E+0	1.94E-1	> C
I	San Onofre	70	0.2	4.08E-3	2.85E-2	> C
S	Standard	0	0	0.00E+0	0.00E+0	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	1.2	6.04E+0	2.22E-1
Total	1.3	6.62E+0	2.22E-1

Current Waste Inventory: Seabrook 1
1995 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Sequoyah 1
1981 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Sequoyah 2
1982 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Shoreham
1995 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/4; 80 Mil Thick	0	0	0.00E+0	N/A	N/A
B	BWR/4,5,100 Mil Thic	0	0	0.00E+0	0.00E+0	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: South Texas 1
1988 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: South Texas 2
1989 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: St. Lucie 1
1976 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Part Length, Ver. 2	7	0.26	1.22E+0	N/A	N/A
C	Full Length	57	2	9.91E+0	4.09E-1	> C
I	Millstone 2	131	0.75	9.42E-2	9.91E-2	> C
S	137 Inch Core	1	0.0049	1.04E-3	7.09E-4	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	2.7	1.00E+1	5.09E-1
Total	3	1.12E+1	5.09E-1

Current Waste Inventory: St. Lucie 2
1983 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	St. Lucie 2 Part Len	3	0.11	5.25E-1	N/A	N/A
C	St. Lucie 2 Full Len	36	1.1	6.30E+0	2.05E-1	> C
I	St. Lucie 2	82	0.26	5.43E-2	3.34E-2	> C
S	Standard	1	0.0037	8.40E-4	6.39E-4	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	1.3	6.36E+0	2.39E-1
Total	1.5	6.88E+0	2.39E-1

Current Waste Inventory: Summer
1984 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Surry 1
1972 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Standard	N/A	0.075	1.83E-1	N/A	N/A
G	Standard	N/A	0.0049	1.19E-2	6.12E-4	> C
P	WABA (8-Rod)	N/A	0.01	1.79E-1	1.71E-3	> C
P	WABA (20-Rod)	N/A	0.019	1.79E-1	3.35E-3	> C
P	Short WABA (4-Rod)	N/A	0.0075	1.71E-1	1.09E-3	> C
P	Short WABA (12-Rod)	N/A	0.013	1.71E-1	2.05E-3	> C
P	BPA (4-Rod)	N/A	0.0093	1.82E-1	1.59E-3	> C
P	BPA (10-Rod)	N/A	0.015	1.82E-1	2.99E-3	> C
P	BPA (20-Rod)	N/A	0.024	1.82E-1	5.31E-3	> C
S	Primary, Version 1	N/A	0.024	1.84E-1	3.80E-3	> C
S	Primary, Version 2	N/A	0.024	1.84E-1	3.80E-3	> C
S	Primary, Version 3	N/A	0.015	1.82E-1	3.42E-3	> C
S	Secondary, 116 Inch	N/A	0.013	1.35E-1	8.17E-4	> C
S	Secondary, 143 Inch	N/A	0.011	1.67E-1	1.16E-3	> C
S	Secondary, 157 Inch	N/A	0.0086	1.82E-1	8.18E-4	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Surry 2
1973 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Standard	N/A	0.075	1.83E-1	N/A	N/A
G	Standard	N/A	0.0049	1.19E-2	6.12E-4	> C
P	WABA (8-Rod)	N/A	0.01	1.79E-1	1.71E-3	> C
P	WABA (20-Rod)	N/A	0.019	1.79E-1	3.35E-3	> C
P	Short WABA (4-Rod)	N/A	0.0075	1.71E-1	1.09E-3	> C
P	Short WABA (12-Rod)	N/A	0.013	1.71E-1	2.05E-3	> C
P	BPA (4-Rod)	N/A	0.0093	1.82E-1	1.59E-3	> C
P	BPA (10-Rod)	N/A	0.015	1.82E-1	2.99E-3	> C
P	BPA (20-Rod)	N/A	0.024	1.82E-1	5.31E-3	> C
S	Primary, Version 1	N/A	0.024	1.84E-1	3.80E-3	> C
S	Primary, Version 2	N/A	0.024	1.84E-1	3.80E-3	> C
S	Primary, Version 3	N/A	0.015	1.82E-1	3.42E-3	> C
S	Secondary, 116 Inch	N/A	0.013	1.35E-1	8.17E-4	> C
S	Secondary, 143 Inch	N/A	0.011	1.67E-1	1.16E-3	> C
S	Secondary, 157 Inch	N/A	0.0086	1.82E-1	8.18E-4	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Susquehanna 1
1983 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/4; 80 Mil Thick	1188	37	9.61E+1	N/A	N/A
B	BWR/4,5,100 Mil Thic	1188	46	9.61E+1	7.06E+0	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	46	9.61E+1	7.06E+0
Total	84	1.92E+2	7.06E+0

Current Waste Inventory: Susquehanna 2
1985 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/4; 80 Mil Thick	848	27	6.86E+1	N/A	N/A
B	BWR/4,5,100 Mil Thic	848	33	6.86E+1	5.04E+0	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	33	6.86E+1	5.04E+0
Total	60	1.37E+2	5.04E+0

Current Waste Inventory: Three Mile Island 1
1974 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Standard	65	3.8	1.24E+1	N/A	N/A
G	Standard	N/A	0.0072	1.91E-2	8.69E-4	> C
P	Gray Ax. Power Shap.	N/A	0.032	1.91E-1	3.96E-3	> C
P	Burnable Poison	N/A	0.026	1.84E-1	4.72E-3	> C
P	Axial Power Shap.	N/A	0.026	1.91E-1	2.90E-3	> C
S	Primary Source	N/A	0.00045	1.74E-1	5.49E-5	> C
S	Regenerative	2	0.042	3.44E-1	2.05E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0.042	3.44E-1	2.05E-3
Total	3.9	1.28E+1	2.05E-3

Current Waste Inventory: Trojan
1976 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Turkey Point 3
1972 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Standard	N/A	0.075	1.83E-1	N/A	N/A
G	Standard	N/A	0.0049	1.19E-2	6.12E-4	> C
P	WABA (8-Rod)	N/A	0.01	1.79E-1	1.71E-3	> C
P	WABA (20-Rod)	N/A	0.019	1.79E-1	3.35E-3	> C
P	Short WABA (4-Rod)	N/A	0.0075	1.71E-1	1.09E-3	> C
P	Short WABA (12-Rod)	N/A	0.013	1.71E-1	2.05E-3	> C
P	BPA (4-Rod)	N/A	0.0093	1.82E-1	1.59E-3	> C
P	BPA (10-Rod)	N/A	0.015	1.82E-1	2.99E-3	> C
P	BPA (20-Rod)	N/A	0.024	1.82E-1	5.31E-3	> C
S	Primary, Version 1	N/A	0.024	1.84E-1	3.80E-3	> C
S	Primary, Version 2	N/A	0.024	1.84E-1	3.80E-3	> C
S	Primary, Version 3	N/A	0.015	1.82E-1	3.42E-3	> C
S	Secondary, 116 Inch	N/A	0.013	1.35E-1	8.17E-4	> C
S	Secondary, 143 Inch	N/A	0.011	1.67E-1	1.16E-3	> C
S	Secondary, 157 Inch	N/A	0.0086	1.82E-1	8.18E-4	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Turkey Point 4
1973 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Standard	N/A	0.075	1.83E-1	N/A	N/A
G	Standard	N/A	0.0049	1.19E-2	6.12E-4	> C
P	WABA (8-Rod)	N/A	0.01	1.79E-1	1.71E-3	> C
P	WABA (20-Rod)	N/A	0.019	1.79E-1	3.35E-3	> C
P	Short WABA (4-Rod)	N/A	0.0075	1.71E-1	1.09E-3	> C
P	Short WABA (12-Rod)	N/A	0.013	1.71E-1	2.05E-3	> C
P	BPA (4-Rod)	N/A	0.0093	1.82E-1	1.59E-3	> C
P	BPA (10-Rod)	N/A	0.015	1.82E-1	2.99E-3	> C
P	BPA (20-Rod)	N/A	0.024	1.82E-1	5.31E-3	> C
S	Primary, Version 1	N/A	0.024	1.84E-1	3.80E-3	> C
S	Primary, Version 2	N/A	0.024	1.84E-1	3.80E-3	> C
S	Primary, Version 3	N/A	0.015	1.82E-1	3.42E-3	> C
S	Secondary, 116 Inch	N/A	0.013	1.35E-1	8.17E-4	> C
S	Secondary, 143 Inch	N/A	0.011	1.67E-1	1.16E-3	> C
S	Secondary, 157 Inch	N/A	0.0086	1.82E-1	8.18E-4	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Vermont Yankee
1972 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/4; 80 Mil Thick	1472	46	1.19E+2	N/A	N/A
B	BWR/4,5,100 Mil Thic	1472	57	1.19E+2	8.75E+0	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	57	1.19E+2	8.75E+0
Total	100	2.38E+2	8.75E+0

Current Waste Inventory: Vogtle 1
1987 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Vogtle 2
1989 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Washington Nuclear 1
1995 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Washington Nuclear 2
1984 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/4,5,100 Mil Thic	1018	40	8.23E+1	N/A	N/A

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	40	8.23E+1	0.00E+0

Current Waste Inventory: Washington Nuclear 3
1995 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Waterford 3
1985 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	San Onofre Part Len	2	0.083	3.89E-1	N/A	N/A
C	San Onofre Full Len	26	0.85	5.06E+0	1.62E-1	> C
I	Waterford	58	0.19	4.17E-2	2.67E-2	> C
S	Standard	0	0	0.00E+0	0.00E+0	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	1	5.10E+0	1.89E-1
Total	1.1	5.49E+0	1.89E-1

Current Waste Inventory: Watts Bar 1
1992 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Watts Bar 2
1995 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Wolf Creek
1985 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Yankee-Rowe
1961 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Zion 1
1973 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Standard	N/A	0.075	1.83E-1	N/A	N/A
G	Standard	N/A	0.0049	1.19E-2	6.12E-4	> C
P	WABA (8-Rod)	N/A	0.01	1.79E-1	1.71E-3	> C
P	WABA (20-Rod)	N/A	0.019	1.79E-1	3.35E-3	> C
P	Short WABA (4-Rod)	N/A	0.0075	1.71E-1	1.09E-3	> C
P	Short WABA (12-Rod)	N/A	0.013	1.71E-1	2.05E-3	> C
P	BPA (4-Rod)	N/A	0.0093	1.82E-1	1.59E-3	> C
P	BPA (10-Rod)	N/A	0.015	1.82E-1	2.99E-3	> C
P	BPA (20-Rod)	N/A	0.024	1.82E-1	5.31E-3	> C
S	Primary, Version 1	N/A	0.024	1.84E-1	3.80E-3	> C
S	Primary, Version 2	N/A	0.024	1.84E-1	3.80E-3	> C
S	Primary, Version 3	N/A	0.015	1.82E-1	3.42E-3	> C
S	Secondary, 116 Inch	N/A	0.013	1.35E-1	8.17E-4	> C
S	Secondary, 143 Inch	N/A	0.011	1.67E-1	1.16E-3	> C
S	Secondary, 157 Inch	N/A	0.0086	1.82E-1	8.18E-4	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Current Waste Inventory: Zion 2
1974 - 1990

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Standard	N/A	0.075	1.83E-1	N/A	N/A
G	Standard	N/A	0.0049	1.19E-2	6.12E-4	> C
P	WABA (8-Rod)	N/A	0.01	1.79E-1	1.71E-3	> C
P	WABA (20-Rod)	N/A	0.019	1.79E-1	3.35E-3	> C
P	Short WABA (4-Rod)	N/A	0.0075	1.71E-1	1.09E-3	> C
P	Short WABA (12-Rod)	N/A	0.013	1.71E-1	2.05E-3	> C
P	BPA (4-Rod)	N/A	0.0093	1.82E-1	1.59E-3	> C
P	BPA (10-Rod)	N/A	0.015	1.82E-1	2.99E-3	> C
P	BPA (20-Rod)	N/A	0.024	1.82E-1	5.31E-3	> C
S	Primary, Version 1	N/A	0.024	1.84E-1	3.80E-3	> C
S	Primary, Version 2	N/A	0.024	1.84E-1	3.80E-3	> C
S	Primary, Version 3	N/A	0.015	1.82E-1	3.42E-3	> C
S	Secondary, 116 Inch	N/A	0.013	1.35E-1	8.17E-4	> C
S	Secondary, 143 Inch	N/A	0.011	1.67E-1	1.16E-3	> C
S	Secondary, 157 Inch	N/A	0.0086	1.82E-1	8.18E-4	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

HARDWARE TOTALS	Num. of Types	Number	Weight	Cu. Vol.	Red. Vol.	% GTCC
BWR Fuel Channels	1	29665	1200	2.40E+3	1.76E+2	100.0
Control Elements	7	622	24	1.15E+2	4.48E+0	100.0
Guide Tube Plugs	0	0	0	0.00E+0	0.00E+0	0.0
Instrumentation	9	1316	7.4	1.16E+0	9.72E-1	100.0
Burnable Poisons	0	0	0	0.00E+0	0.00E+0	0.0
Incore Sources	6	29	0.35	2.42E+0	2.28E-2	100.0
TOTALS	23	31632	1200	2.52E+3	1.82E+2	100.0

Total Estimated: 95
Number Incomplete: 72
Percentage Not Represented: 75.8

APPENDIX B
ESTIMATE OF TOTAL NON-FUEL ASSEMBLY
HARDWARE INVENTORIES OUT TO 2010

The following is the complete text of the 2010 NFA hardware estimate performed by the Hardware Waste Expert System. Some explanation of the results may be required. All NFA hardware records listed within the CDB are presented for each reactor. Where the available information is incomplete, the code "N/A" has been substituted. For records where "N/A" has been entered in the number column, the information presented in the remaining columns represents the information for a single hardware element. In all other cases, the values are totals for the entire inventory of those components.

The summary totals presented at the end of each reactor listing may not total among themselves. The "Total LECC" heading, for example, includes only those records for which all the calculations could be performed and which classify as Class A, B, or C LLW. Similarly, the "Total GTCC" heading includes only those complete records which classify as GTCC waste. The final "Total," however, includes all records which fell into the previous two categories plus any records for which all information except the Reduced Volume and Classification are available.

The category headings should be self-explanatory, but a

brief explanation of each is presented here. The "Type" heading represents the type of NFA hardware component being listed. The codes are as follows:

B = BWR Fuel Channel
I = Incore Instrumentation
C = Control Elements
P = Burnable Poisons
G = Guide Tube Plugs
S = Neutron Sources

The "Name" heading lists the name of the NFA hardware component as listed by the CDB. The "Number" column indicates the total number of the components which are expected to have been discharged to date. The "Weight" column represents the total weight of the discharged hardware components or the weight of a single component if a "N/A" is present in the "Number" column. "Cu. Vol." stands for the Cubic Volume of the hardware components as discussed in the main text, namely the volume based on the hardware's outer dimensions. Similarly, "Red. Vol." is the Reduced Volume of the hardware or the volume based on the actual volume of the hardware's materials of construction. Both volumes represent the total hardware volume of the components or the volume of a single component if a "N/A" is placed in the "Number" column. Finally, the "Class" column lists the 10CFR61 waste classification of the hardware as calculated by the HWES. The code "> C" indicates waste which classifies as GTCC waste, while the code "<=C" indicates waste which classifies as Class A, B, or C LLW.

Future Waste Inventory: Arkansas 1
1974 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Standard	146	8.6	2.79E+1	9.08E-1	> C
G	Standard	N/A	0.0072	1.91E-2	8.69E-4	> C
P	Gray Ax. Power Shap.	N/A	0.032	1.91E-1	3.96E-3	> C
P	Burnable Poison	N/A	0.026	1.84E-1	4.72E-3	> C
P	Axial Power Shap.	N/A	0.026	1.91E-1	2.90E-3	> C
S	Primary Source	N/A	0.00045	1.74E-1	5.49E-5	> C
S	Regenerative	4	0.084	6.88E-1	4.11E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	8.7	2.86E+1	9.12E-1
Total	8.7	2.86E+1	9.12E-1

Future Waste Inventory: Arkansas 2
1980 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	ANO2 Part Length	15	0.62	2.92E+0	N/A	N/A
C	ANO2 Full Length	137	4.4	2.66E+1	8.55E-1	> C
I	ANO2	276	0.88	1.61E-2	1.19E-1	> C
S	Standard	4	0.015	3.36E-3	2.56E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	5.3	2.67E+1	9.76E-1
Total	5.9	2.96E+1	9.76E-1

Future Waste Inventory: Beaver Valley 1
1977 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: Beaver Valley 2
1987 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: Bellefonte 1
1995 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: Bellefonte 2
1995 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: Big Rock Point
1962 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: Braidwood 1
1988 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: Braidwood 2
1988 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: Browns Ferry 1
1974 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/4; 80 Mil Thick	6112	1.9E+2	4.94E+2	N/A	N/A
B	BWR/4,5,100 Mil Thic	6112	2.4E+2	4.94E+2	3.63E+1	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	2.4E+2	4.94E+2	3.63E+1
Total	4.3E+2	9.89E+2	3.63E+1

Future Waste Inventory: Browns Ferry 2
1975 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/4; 80 Mil Thick	5942	1.9E+2	4.81E+2	N/A	N/A
B	BWR/4,5,100 Mil Thic	5942	2.3E+2	4.81E+2	3.53E+1	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	2.3E+2	4.81E+2	3.53E+1
Total	4.2E+2	9.61E+2	3.53E+1

Future Waste Inventory: Browns Ferry 3
1977 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/4; 80 Mil Thick	5602	1.8E+2	4.53E+2	N/A	N/A
B	BWR/4,5,100 Mil Thic	5602	2.2E+2	4.53E+2	3.33E+1	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	2.2E+2	4.53E+2	3.33E+1
Total	3.9E+2	9.06E+2	3.33E+1

Future Waste Inventory: Brunswick 1
1977 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/4; 80 Mil Thick	4106	1.3E+2	3.32E+2	N/A	N/A
B	BWR/4,5,100 Mil Thic	4106	1.6E+2	3.32E+2	2.44E+1	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	1.6E+2	3.32E+2	2.44E+1
Total	2.9E+2	6.64E+2	2.44E+1

Future Waste Inventory: Brunswick 2
1975 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/4; 80 Mil Thick	4355	1.4E+2	3.52E+2	N/A	N/A
B	BWR/4,5,100 Mil Thic	4355	1.7E+2	3.52E+2	2.59E+1	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	1.7E+2	3.52E+2	2.59E+1
Total	3.1E+2	7.05E+2	2.59E+1

Future Waste Inventory: Byron 1
1985 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: Byron 2
1987 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: Callaway
1985 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: Calvert Cliffs 1
1975 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Part Length, Ver. 1	26	0.74	4.52E+0	N/A	N/A
C	Full Length	142	4.9	2.47E+1	1.02E+0	> C
I	Calvert Cliffs	329	1.7	2.55E-1	2.29E-1	> C
S	137 Inch Core	4	0.02	4.18E-3	2.84E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	6.7	2.49E+1	1.25E+0
Total	7.5	2.95E+1	1.25E+0

Future Waste Inventory: Calvert Cliffs 2
1977 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Part Length, Ver. 1	24	0.69	4.17E+0	N/A	N/A
C	Full Length	134	4.7	2.33E+1	9.61E-1	> C
I	Calvert Cliffs	310	1.6	2.40E-1	2.15E-1	> C
S	137 Inch Core	4	0.02	4.18E-3	2.84E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	6.3	2.35E+1	1.18E+0
Total	7	2.77E+1	1.18E+0

Future Waste Inventory: Catawba 1
1985 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: Catawba 2
1986 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: Clinton
1987 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/6; 120 Mil Thick	2269	1.1E+2	1.85E+2	N/A	N/A

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	1.1E+2	1.85E+2	0.00E+0

Future Waste Inventory: Comanche Peak 1
1989 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: Comanche Peak 2
1992 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: Cook 1
1975 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Standard	N/A	0.075	1.83E-1	N/A	N/A
G	Standard	N/A	0.0049	1.19E-2	6.12E-4	> C
P	WABA (8-Rod)	N/A	0.01	1.79E-1	1.71E-3	> C
P	WABA (20-Rod)	N/A	0.019	1.79E-1	3.35E-3	> C
P	Short WABA (4-Rod)	N/A	0.0075	1.71E-1	1.09E-3	> C
P	Short WABA (12-Rod)	N/A	0.013	1.71E-1	2.05E-3	> C
P	BPA (4-Rod)	N/A	0.0093	1.82E-1	1.59E-3	> C
P	BPA (10-Rod)	N/A	0.015	1.82E-1	2.99E-3	> C
P	BPA (20-Rod)	N/A	0.024	1.82E-1	5.31E-3	> C
S	Primary, Version 1	N/A	0.024	1.84E-1	3.80E-3	> C
S	Primary, Version 2	N/A	0.024	1.84E-1	3.80E-3	> C
S	Primary, Version 3	N/A	0.015	1.82E-1	3.42E-3	> C
S	Secondary, 116 Inch	N/A	0.013	1.35E-1	8.17E-4	> C
S	Secondary, 143 Inch	N/A	0.011	1.67E-1	1.16E-3	> C
S	Secondary, 157 Inch	N/A	0.0086	1.82E-1	8.18E-4	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: Cook 2
1978 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: Cooper Station
1974 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/4; 80 Mil Thick	4384	1.4E+2	3.55E+2	N/A	N/A
B	BWR/4,5,100 Mil Thic	4384	1.7E+2	3.55E+2	2.61E+1	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	1.7E+2	3.55E+2	2.61E+1
Total	3.1E+2	7.09E+2	2.61E+1

Future Waste Inventory: Crystal River 3
1977 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Standard	134	7.9	2.56E+1	N/A	N/A
G	Standard	N/A	0.0072	1.91E-2	8.69E-4	> C
P	Gray Ax. Power Shap.	N/A	0.032	1.91E-1	3.96E-3	> C
P	Burnable Poison	N/A	0.026	1.84E-1	4.72E-3	> C
P	Axial Power Shap.	N/A	0.026	1.91E-1	2.90E-3	> C
S	Primary Source	N/A	0.00045	1.74E-1	5.49E-5	> C
S	Regenerative	4	0.084	6.88E-1	4.11E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0.084	6.88E-1	4.11E-3
Total	8	2.63E+1	4.11E-3

Future Waste Inventory: Davis-Besse
1977 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Standard	134	7.9	2.56E+1	N/A	N/A
G	Standard	N/A	0.0072	1.91E-2	8.69E-4	> C
P	Gray Ax. Power Shap.	N/A	0.032	1.91E-1	3.96E-3	> C
P	Burnable Poison	N/A	0.026	1.84E-1	4.72E-3	> C
P	Axial Power Shap.	N/A	0.026	1.91E-1	2.90E-3	> C
S	Primary Source	N/A	0.00045	1.74E-1	5.49E-5	> C
S	Regenerative	4	0.084	6.88E-1	4.11E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0.084	6.88E-1	4.11E-3
Total	8	2.63E+1	4.11E-3

Future Waste Inventory: Diablo Canyon 1
1985 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: Diablo Canyon 2
1986 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: Dresden 1
1960 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	Dresden, 60 Mil	4337	59	1.66E+2	N/A	N/A

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	59	1.66E+2	0.00E+0

Future Waste Inventory: Dresden 2
1970 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/2,3;80 Mil Thick	6435	2E+2	5.06E+2	N/A	N/A

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	2E+2	5.06E+2	0.00E+0

Future Waste Inventory: Dresden 3
1971 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/2,3;80 Mil Thick	6274	1.9E+2	4.93E+2	N/A	N/A

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	1.9E+2	4.93E+2	0.00E+0

Future Waste Inventory: Duane Arnold
1975 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/4; 80 Mil Thick	2862	90	2.31E+2	N/A	N/A
B	BWR/4,5,100 Mil Thic	2862	1.1E+2	2.31E+2	1.70E+1	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	1.1E+2	2.31E+2	1.70E+1
Total	2E+2	4.63E+2	1.70E+1

Future Waste Inventory: Enrico Fermi 2
1988 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/4; 80 Mil Thick	3735	1.2E+2	3.02E+2	N/A	N/A
B	BWR/4,5,100 Mil Thic	3735	1.5E+2	3.02E+2	2.22E+1	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	1.5E+2	3.02E+2	2.22E+1
Total	2.6E+2	6.04E+2	2.22E+1

Future Waste Inventory: Farley 1
1977 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: Farley 2
1981 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: Fitzpatrick
1975 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/4; 80 Mil Thick	4355	1.4E+2	3.52E+2	N/A	N/A
B	BWR/4,5,100 Mil Thic	4355	1.7E+2	3.52E+2	2.59E+1	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	1.7E+2	3.52E+2	2.59E+1
Total	3.1E+2	7.05E+2	2.59E+1

Future Waste Inventory: Fort Calhoun
1973 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Part Length	9	0.26	1.47E+0	N/A	N/A
C	Full Length	104	3.1	1.70E+1	7.02E-1	> C
I	Ft. Calhoun	216	1.1	1.59E-1	1.49E-1	> C
S	128 Inch Core	4	0.019	3.94E-3	2.18E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	4.3	1.72E+1	8.53E-1
Total	4.6	1.86E+1	8.53E-1

Future Waste Inventory: Ginna
1970 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Standard	N/A	0.058	1.56E-1	N/A	N/A
C	Short, Ver. 1	N/A	0.058	1.55E-1	5.30E-3	> C
C	Short, Ver. 2	N/A	0.049	1.32E-1	5.27E-3	> C
G	Water Displacement	N/A	0.0093	1.54E-1	1.14E-3	> C
G	Standard	N/A	0.0043	1.19E-2	5.38E-4	> C
P	(4-Rod)	N/A	0.0077	1.54E-1	1.46E-3	> C
P	(12-Rod)	N/A	0.015	1.54E-1	3.31E-3	> C
P	BPA (16-Rod)	N/A	0.018	1.54E-1	4.22E-3	> C
P	WABA (4-Rod)	N/A	0.0071	1.52E-1	1.07E-3	> C
P	WABA (12-Rod)	N/A	0.013	1.52E-1	2.17E-3	> C
P	WABA (16-Rod)	N/A	0.016	1.52E-1	2.73E-3	> C
S	Primary, Version 1	N/A	0.022	1.24E-1	3.77E-3	> C
S	Primary, Version 2	N/A	0.022	1.56E-1	3.78E-3	> C
S	Primary, Version 3	N/A	0.022	1.56E-1	3.78E-3	> C
S	Secondary, 116 Inch	N/A	0.01	1.15E-1	9.53E-4	> C
S	Secondary, 137 Inch	N/A	0.011	1.36E-1	1.00E-3	> C
S	Secondary, 143 Inch	N/A	0.01	1.41E-1	1.04E-3	> C
S	Secondary, 157 Inch	N/A	0.013	1.55E-1	1.04E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: Grand Gulf 1
1985 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/6; 120 Mil Thick	3266	1.5E+2	2.67E+2	N/A	N/A

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	1.5E+2	2.67E+2	0.00E+0

Future Waste Inventory: Grand Gulf 2
1995 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/6; 120 Mil Thick	1960	92	1.60E+2	N/A	N/A

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	92	1.60E+2	0.00E+0

Future Waste Inventory: Haddam Neck
1968 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Standard	N/A	0.075	1.84E-1	N/A	N/A
G	Standard	N/A	0.0049	1.20E-2	6.12E-4	> C
P	WABA (8-Rod)	N/A	0.01	1.81E-1	1.71E-3	> C
P	WABA (20-Rod)	N/A	0.019	1.81E-1	3.35E-3	> C
P	Short WABA (4-Rod)	N/A	0.0075	1.72E-1	1.09E-3	> C
P	Short WABA (12-Rod)	N/A	0.013	1.72E-1	2.05E-3	> C
P	BPA (4-Rod)	N/A	0.0093	1.83E-1	1.59E-3	> C
P	BPA (10-Rod)	N/A	0.015	1.83E-1	2.99E-3	> C
P	BPA (20-Rod)	N/A	0.024	1.83E-1	5.31E-3	> C
S	Primary, Version 1	N/A	0.024	1.86E-1	3.80E-3	> C
S	Primary, Version 2	N/A	0.024	1.86E-1	3.80E-3	> C
S	Primary, Version 3	N/A	0.015	1.83E-1	3.42E-3	> C
S	Secondary, 116 Inch	N/A	0.013	1.36E-1	8.17E-4	> C
S	Secondary, 143 Inch	N/A	0.011	1.68E-1	1.16E-3	> C
S	Secondary, 157 Inch	N/A	0.0086	1.83E-1	8.18E-4	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: Harris
1987 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: Hatch 1
1975 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/4; 80 Mil Thick	4355	1.4E+2	3.52E+2	N/A	N/A
B	BWR/4,5,100 Mil Thic	4355	1.7E+2	3.52E+2	2.59E+1	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	1.7E+2	3.52E+2	2.59E+1
Total	3.1E+2	7.05E+2	2.59E+1

Future Waste Inventory: Hatch 2
1979 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/4; 80 Mil Thick	3857	1.2E+2	3.12E+2	N/A	N/A
B	BWR/4,5,100 Mil Thic	3857	1.5E+2	3.12E+2	2.29E+1	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	1.5E+2	3.12E+2	2.29E+1
Total	2.7E+2	6.24E+2	2.29E+1

Future Waste Inventory: Hope Creek
1987 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/4; 80 Mil Thick	3904	1.2E+2	3.16E+2	N/A	N/A
B	BWR/4,5,100 Mil Thic	3904	1.5E+2	3.16E+2	2.32E+1	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	1.5E+2	3.16E+2	2.32E+1
Total	2.7E+2	6.32E+2	2.32E+1

Future Waste Inventory: Humboldt Bay
1963 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	Humboldt Bay	1528	16	4.82E+1	N/A	N/A

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	16	4.82E+1	0.00E+0

Future Waste Inventory: Indian Point 1
1962 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: Indian Point 2
1974 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Standard	N/A	0.075	1.83E-1	N/A	N/A
G	Standard	N/A	0.0049	1.19E-2	6.12E-4	> C
P	WABA (8-Rod)	N/A	0.01	1.79E-1	1.71E-3	> C
P	WABA (20-Rod)	N/A	0.019	1.79E-1	3.35E-3	> C
P	Short WABA (4-Rod)	N/A	0.0075	1.71E-1	1.09E-3	> C
P	Short WABA (12-Rod)	N/A	0.013	1.71E-1	2.05E-3	> C
P	BPA (4-Rod)	N/A	0.0093	1.82E-1	1.59E-3	> C
P	BPA (10-Rod)	N/A	0.015	1.82E-1	2.99E-3	> C
P	BPA (20-Rod)	N/A	0.024	1.82E-1	5.31E-3	> C
S	Primary, Version 1	N/A	0.024	1.84E-1	3.80E-3	> C
S	Primary, Version 2	N/A	0.024	1.84E-1	3.80E-3	> C
S	Primary, Version 3	N/A	0.015	1.82E-1	3.42E-3	> C
S	Secondary, 116 Inch	N/A	0.013	1.35E-1	8.17E-4	> C
S	Secondary, 143 Inch	N/A	0.011	1.67E-1	1.16E-3	> C
S	Secondary, 157 Inch	N/A	0.0086	1.82E-1	8.18E-4	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: Indian Point 3
1976 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Standard	N/A	0.075	1.83E-1	N/A	N/A
G	Standard	N/A	0.0049	1.19E-2	6.12E-4	> C
P	WABA (8-Rod)	N/A	0.01	1.79E-1	1.71E-3	> C
P	WABA (20-Rod)	N/A	0.019	1.79E-1	3.35E-3	> C
P	Short WABA (4-Rod)	N/A	0.0075	1.71E-1	1.09E-3	> C
P	Short WABA (12-Rod)	N/A	0.013	1.71E-1	2.05E-3	> C
P	BPA (4-Rod)	N/A	0.0093	1.82E-1	1.59E-3	> C
P	BPA (10-Rod)	N/A	0.015	1.82E-1	2.99E-3	> C
P	BPA (20-Rod)	N/A	0.024	1.82E-1	5.31E-3	> C
S	Primary, Version 1	N/A	0.024	1.84E-1	3.80E-3	> C
S	Primary, Version 2	N/A	0.024	1.84E-1	3.80E-3	> C
S	Primary, Version 3	N/A	0.015	1.82E-1	3.42E-3	> C
S	Secondary, 116 Inch	N/A	0.013	1.35E-1	8.17E-4	> C
S	Secondary, 143 Inch	N/A	0.011	1.67E-1	1.16E-3	> C
S	Secondary, 157 Inch	N/A	0.0086	1.82E-1	8.18E-4	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: Kewaunee
1974 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Standard	N/A	0.058	1.56E-1	N/A	N/A
C	Short, Ver. 1	N/A	0.058	1.55E-1	5.30E-3	> C
C	Short, Ver. 2	N/A	0.049	1.32E-1	5.27E-3	> C
G	Water Displacement	N/A	0.0093	1.54E-1	1.14E-3	> C
G	Standard	N/A	0.0043	1.19E-2	5.38E-4	> C
P	(4-Rod)	N/A	0.0077	1.54E-1	1.46E-3	> C
P	(12-Rod)	N/A	0.015	1.54E-1	3.31E-3	> C
P	BPA (16-Rod)	N/A	0.018	1.54E-1	4.22E-3	> C
P	WABA (4-Rod)	N/A	0.0071	1.52E-1	1.07E-3	> C
P	WABA (12-Rod)	N/A	0.013	1.52E-1	2.17E-3	> C
P	WABA (16-Rod)	N/A	0.016	1.52E-1	2.73E-3	> C
S	Primary, Version 1	N/A	0.022	1.24E-1	3.77E-3	> C
S	Primary, Version 2	N/A	0.022	1.56E-1	3.78E-3	> C
S	Primary, Version 3	N/A	0.022	1.56E-1	3.78E-3	> C
S	Secondary, 116 Inch	N/A	0.01	1.15E-1	9.53E-4	> C
S	Secondary, 137 Inch	N/A	0.011	1.36E-1	1.00E-3	> C
S	Secondary, 143 Inch	N/A	0.01	1.41E-1	1.04E-3	> C
S	Secondary, 157 Inch	N/A	0.013	1.55E-1	1.04E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: LaCrosse
1969 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: LaSalle 1
1982 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/4,5,100 Mil Thic	4753	1.9E+2	3.84E+2	N/A	N/A

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	1.9E+2	3.84E+2	0.00E+0

Future Waste Inventory: LaSalle 2
1984 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/4,5,100 Mil Thic	4414	1.7E+2	3.57E+2	N/A	N/A

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	1.7E+2	3.57E+2	0.00E+0

Future Waste Inventory: Limerick 1
1986 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/4; 80 Mil Thick	4074	1.3E+2	3.30E+2	N/A	N/A
B	BWR/4,5,100 Mil Thic	4074	1.6E+2	3.30E+2	2.42E+1	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	1.6E+2	3.30E+2	2.42E+1
Total	2.9E+2	6.59E+2	2.42E+1

Future Waste Inventory: Limerick 2
1990 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/4; 80 Mil Thick	3395	1.1E+2	2.75E+2	N/A	N/A
B	BWR/4,5,100 Mil Thic	3395	1.3E+2	2.75E+2	2.02E+1	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	1.3E+2	2.75E+2	2.02E+1
Total	2.4E+2	5.49E+2	2.02E+1

Future Waste Inventory: Maine Yankee
1972 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Part Length, Ver. 3	28	1.3	4.87E+0	N/A	N/A
C	Full Length	155	5.4	2.69E+1	1.11E+0	> C
S	137 Inch Core	4	0.02	4.18E-3	2.84E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	5.4	2.70E+1	1.11E+0
Total	6.7	3.18E+1	1.11E+0

Future Waste Inventory: McGuire 1
1981 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: McGuire 2
1984 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: Millstone 1
1970 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/2,3;80 Mil Thick	5155	1.6E+2	4.05E+2	N/A	N/A

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	1.6E+2	4.05E+2	0.00E+0

Future Waste Inventory: Millstone 2
1975 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Part Length, Ver. 2	17	0.64	2.96E+0	N/A	N/A
C	Full Length	142	4.9	2.47E+1	1.02E+0	> C
I	Millstone 2	329	1.9	2.37E-1	2.49E-1	> C
S	137 Inch Core	4	0.02	4.18E-3	2.84E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	6.9	2.49E+1	1.27E+0
Total	7.5	2.79E+1	1.27E+0

Future Waste Inventory: Millstone 3
1986 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: Monticello
1971 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/2,3;80 Mil Thick	4194	1.3E+2	3.30E+2	N/A	N/A

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	1.3E+2	3.30E+2	0.00E+0

Future Waste Inventory: Nine Mile Point 1
1969 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/2,3;80 Mil Thick	4728	1.4E+2	3.71E+2	N/A	N/A

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	1.4E+2	3.71E+2	0.00E+0

Future Waste Inventory: Nine Mile Point 2
1988 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/4,5,100 Mil Thic	3735	1.5E+2	3.02E+2	N/A	N/A

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	1.5E+2	3.02E+2	0.00E+0

Future Waste Inventory: North Anna 1
1978 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: North Anna 2
1980 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: Oconee 1
1973 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Standard	150	8.8	2.87E+1	N/A	N/A
G	Standard	N/A	0.0072	1.91E-2	8.69E-4	> C
P	Gray Ax. Power Shap.	N/A	0.032	1.91E-1	3.96E-3	> C
P	Burnable Poison	N/A	0.026	1.84E-1	4.72E-3	> C
P	Axial Power Shap.	N/A	0.026	1.91E-1	2.90E-3	> C
S	Primary Source	N/A	0.00045	1.74E-1	5.49E-5	> C
S	Regenerative	4	0.084	6.88E-1	4.11E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0.084	6.88E-1	4.11E-3
Total	8.9	2.93E+1	4.11E-3

Future Waste Inventory: Oconee 2
1974 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Standard	146	8.6	2.79E+1	N/A	N/A
G	Standard	N/A	0.0072	1.91E-2	8.69E-4	> C
P	Gray Ax. Power Shap.	N/A	0.032	1.91E-1	3.96E-3	> C
P	Burnable Poison	N/A	0.026	1.84E-1	4.72E-3	> C
P	Axial Power Shap.	N/A	0.026	1.91E-1	2.90E-3	> C
S	Primary Source	N/A	0.00045	1.74E-1	5.49E-5	> C
S	Regenerative	4	0.084	6.88E-1	4.11E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0.084	6.88E-1	4.11E-3
Total	8.7	2.86E+1	4.11E-3

Future Waste Inventory: Oconee 3
1974 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Standard	146	8.6	2.79E+1	N/A	N/A
G	Standard	N/A	0.0072	1.91E-2	8.69E-4	> C
P	Gray Ax. Power Shap.	N/A	0.032	1.91E-1	3.96E-3	> C
P	Burnable Poison	N/A	0.026	1.84E-1	4.72E-3	> C
P	Axial Power Shap.	N/A	0.026	1.91E-1	2.90E-3	> C
S	Primary Source	N/A	0.00045	1.74E-1	5.49E-5	> C
S	Regenerative	4	0.084	6.88E-1	4.11E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0.084	6.88E-1	4.11E-3
Total	8.7	2.86E+1	4.11E-3

Future Waste Inventory: Oyster Creek
1969 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/2,3;80 Mil Thick	4977	1.5E+2	3.91E+2	N/A	N/A

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	1.5E+2	3.91E+2	0.00E+0

Future Waste Inventory: Palisades
1971 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Cruciform Blade	58	5.6	9.77E+0	N/A	N/A
I	Palisades	351	1.5	2.46E-1	1.99E-1	> C
S	Sustaining	4	0.0082	6.96E-4	1.16E-3	> C
S	Start-up	4	0.0082	6.96E-4	1.17E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	1.5	2.47E-1	2.01E-1
Total	7.1	1.00E+1	2.01E-1

Future Waste Inventory: Palo Verde 1
1986 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	SYS80 4 Rod Part Len	19	0.82	5.17E+0	N/A	N/A
C	SYS80 12Rod Full Len	72	6.3	1.96E+1	1.20E+0	> C
I	System 80	306	4.8	1.11E+0	6.18E-1	> C
S	Standard	3	0.011	2.52E-3	1.92E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	11	2.07E+1	1.82E+0
Total	12	2.59E+1	1.82E+0

Future Waste Inventory: Palo Verde 2
1986 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	SYS80 4 Rod Part Len	19	0.82	5.17E+0	N/A	N/A
C	SYS80 12Rod Full Len	72	6.3	1.96E+1	1.20E+0	> C
I	System 80	306	4.8	1.11E+0	6.18E-1	> C
S	Standard	3	0.011	2.52E-3	1.92E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	11	2.07E+1	1.82E+0
Total	12	2.59E+1	1.82E+0

Future Waste Inventory: Palo Verde 3
1988 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	SYS80 4 Rod Part Len	17	0.73	4.62E+0	N/A	N/A
C	SYS80 12Rod Full Len	66	5.8	1.80E+1	1.10E+0	> C
I	System 80	281	4.4	1.02E+0	5.67E-1	> C
S	Standard	3	0.011	2.52E-3	1.92E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	10	1.90E+1	1.67E+0
Total	11	2.36E+1	1.67E+0

Future Waste Inventory: Peach Bottom 2
1974 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/4; 80 Mil Thick	6112	1.9E+2	4.94E+2	N/A	N/A
B	BWR/4,5,100 Mil Thic	6080	2.4E+2	4.92E+2	3.61E+1	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	2.4E+2	4.92E+2	3.61E+1
Total	4.3E+2	9.86E+2	3.61E+1

Future Waste Inventory: Peach Bottom 3
1974 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/4; 80 Mil Thick	6112	1.9E+2	4.94E+2	N/A	N/A
B	BWR/4,5,100 Mil Thic	6080	2.4E+2	4.92E+2	3.61E+1	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	2.4E+2	4.92E+2	3.61E+1
Total	4.3E+2	9.86E+2	3.61E+1

Future Waste Inventory: Perry 1
1987 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/6; 120 Mil Thick	3005	1.4E+2	2.45E+2	N/A	N/A

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	1.4E+2	2.45E+2	0.00E+0

Future Waste Inventory: Perry 2
1995 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/6; 120 Mil Thick	1960	92	1.60E+2	N/A	N/A

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	92	1.60E+2	0.00E+0

Future Waste Inventory: Pilgrim
1972 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/3, Long 80 Mil	4897	1.6E+2	4.06E+2	N/A	N/A

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	1.6E+2	4.06E+2	0.00E+0

Future Waste Inventory: Point Beach 1
1970 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Standard	N/A	0.058	1.56E-1	N/A	N/A
C	Short, Ver. 1	N/A	0.058	1.55E-1	5.30E-3	> C
C	Short, Ver. 2	N/A	0.049	1.32E-1	5.27E-3	> C
G	Water Displacement	N/A	0.0093	1.54E-1	1.14E-3	> C
G	Standard	N/A	0.0043	1.19E-2	5.38E-4	> C
P	(4-Rod)	N/A	0.0077	1.54E-1	1.46E-3	> C
P	(12-Rod)	N/A	0.015	1.54E-1	3.31E-3	> C
P	BPA (16-Rod)	N/A	0.018	1.54E-1	4.22E-3	> C
P	WABA (4-Rod)	N/A	0.0071	1.52E-1	1.07E-3	> C
P	WABA (12-Rod)	N/A	0.013	1.52E-1	2.17E-3	> C
P	WABA (16-Rod)	N/A	0.016	1.52E-1	2.73E-3	> C
S	Primary, Version 1	N/A	0.022	1.24E-1	3.77E-3	> C
S	Primary, Version 2	N/A	0.022	1.56E-1	3.78E-3	> C
S	Primary, Version 3	N/A	0.022	1.56E-1	3.78E-3	> C
S	Secondary, 116 Inch	N/A	0.01	1.15E-1	9.53E-4	> C
S	Secondary, 137 Inch	N/A	0.011	1.36E-1	1.00E-3	> C
S	Secondary, 143 Inch	N/A	0.01	1.41E-1	1.04E-3	> C
S	Secondary, 157 Inch	N/A	0.013	1.55E-1	1.04E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: Point Beach 2
1972 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Standard	N/A	0.058	1.56E-1	N/A	N/A
C	Short, Ver. 1	N/A	0.058	1.55E-1	5.30E-3	> C
C	Short, Ver. 2	N/A	0.049	1.32E-1	5.27E-3	> C
G	Water Displacement	N/A	0.0093	1.54E-1	1.14E-3	> C
G	Standard	N/A	0.0043	1.19E-2	5.38E-4	> C
P	(4-Rod)	N/A	0.0077	1.54E-1	1.46E-3	> C
P	(12-Rod)	N/A	0.015	1.54E-1	3.31E-3	> C
P	BPA (16-Rod)	N/A	0.018	1.54E-1	4.22E-3	> C
P	WABA (4-Rod)	N/A	0.0071	1.52E-1	1.07E-3	> C
P	WABA (12-Rod)	N/A	0.013	1.52E-1	2.17E-3	> C
P	WABA (16-Rod)	N/A	0.016	1.52E-1	2.73E-3	> C
S	Primary, Version 1	N/A	0.022	1.24E-1	3.77E-3	> C
S	Primary, Version 2	N/A	0.022	1.56E-1	3.78E-3	> C
S	Primary, Version 3	N/A	0.022	1.56E-1	3.78E-3	> C
S	Secondary, 116 Inch	N/A	0.01	1.15E-1	9.53E-4	> C
S	Secondary, 137 Inch	N/A	0.011	1.36E-1	1.00E-3	> C
S	Secondary, 143 Inch	N/A	0.01	1.41E-1	1.04E-3	> C
S	Secondary, 157 Inch	N/A	0.013	1.55E-1	1.04E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: Prairie Island 1
1973 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Standard	N/A	0.058	1.56E-1	N/A	N/A
C	Short, Ver. 1	N/A	0.058	1.55E-1	5.30E-3	> C
C	Short, Ver. 2	N/A	0.049	1.32E-1	5.27E-3	> C
G	Water Displacement	N/A	0.0093	1.54E-1	1.14E-3	> C
G	Standard	N/A	0.0043	1.19E-2	5.38E-4	> C
P	(4-Rod)	N/A	0.0077	1.54E-1	1.46E-3	> C
P	(12-Rod)	N/A	0.015	1.54E-1	3.31E-3	> C
P	BPA (16-Rod)	N/A	0.018	1.54E-1	4.22E-3	> C
P	WABA (4-Rod)	N/A	0.0071	1.52E-1	1.07E-3	> C
P	WABA (12-Rod)	N/A	0.013	1.52E-1	2.17E-3	> C
P	WABA (16-Rod)	N/A	0.016	1.52E-1	2.73E-3	> C
S	Primary, Version 1	N/A	0.022	1.24E-1	3.77E-3	> C
S	Primary, Version 2	N/A	0.022	1.56E-1	3.78E-3	> C
S	Primary, Version 3	N/A	0.022	1.56E-1	3.78E-3	> C
S	Secondary, 116 Inch	N/A	0.01	1.15E-1	9.53E-4	> C
S	Secondary, 137 Inch	N/A	0.011	1.36E-1	1.00E-3	> C
S	Secondary, 143 Inch	N/A	0.01	1.41E-1	1.04E-3	> C
S	Secondary, 157 Inch	N/A	0.013	1.55E-1	1.04E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: Prairie Island 2
1974 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Standard	N/A	0.058	1.56E-1	N/A	N/A
C	Short, Ver. 1	N/A	0.058	1.55E-1	5.30E-3	> C
C	Short, Ver. 2	N/A	0.049	1.32E-1	5.27E-3	> C
G	Water Displacement	N/A	0.0093	1.54E-1	1.14E-3	> C
G	Standard	N/A	0.0043	1.19E-2	5.38E-4	> C
P	(4-Rod)	N/A	0.0077	1.54E-1	1.46E-3	> C
P	(12-Rod)	N/A	0.015	1.54E-1	3.31E-3	> C
P	BPA (16-Rod)	N/A	0.018	1.54E-1	4.22E-3	> C
P	WABA (4-Rod)	N/A	0.0071	1.52E-1	1.07E-3	> C
P	WABA (12-Rod)	N/A	0.013	1.52E-1	2.17E-3	> C
P	WABA (16-Rod)	N/A	0.016	1.52E-1	2.73E-3	> C
S	Primary, Version 1	N/A	0.022	1.24E-1	3.77E-3	> C
S	Primary, Version 2	N/A	0.022	1.56E-1	3.78E-3	> C
S	Primary, Version 3	N/A	0.022	1.56E-1	3.78E-3	> C
S	Secondary, 116 Inch	N/A	0.01	1.15E-1	9.53E-4	> C
S	Secondary, 137 Inch	N/A	0.011	1.36E-1	1.00E-3	> C
S	Secondary, 143 Inch	N/A	0.01	1.41E-1	1.04E-3	> C
S	Secondary, 157 Inch	N/A	0.013	1.55E-1	1.04E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: Quad Cities 1
1972 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/2,3;80 Mil Thick	6113	1.9E+2	4.80E+2	N/A	N/A

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	1.9E+2	4.80E+2	0.00E+0

Future Waste Inventory: Quad Cities 2
1972 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/2,3;80 Mil Thick	6113	1.9E+2	4.80E+2	N/A	N/A

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	1.9E+2	4.80E+2	0.00E+0

Future Waste Inventory: Rancho Seco
1975 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Standard	123	7.3	2.35E+1	N/A	N/A
G	Standard	N/A	0.0072	1.91E-2	8.69E-4	> C
P	Gray Ax. Power Shap.	N/A	0.032	1.91E-1	3.96E-3	> C
P	Burnable Poison	N/A	0.026	1.84E-1	4.72E-3	> C
P	Axial Power Shap.	N/A	0.026	1.91E-1	2.90E-3	> C
S	Primary Source	N/A	0.00045	1.74E-1	5.49E-5	> C
S	Regenerative	4	0.084	6.88E-1	4.11E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0.084	6.88E-1	4.11E-3
Total	7.3	2.42E+1	4.11E-3

Future Waste Inventory: River Bend 1
1986 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/6; 120 Mil Thick	2368	1.1E+2	1.93E+2	N/A	N/A

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	1.1E+2	1.93E+2	0.00E+0

Future Waste Inventory: Robinson 2
1971 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Standard	N/A	0.075	1.83E-1	N/A	N/A
G	Standard	N/A	0.0049	1.19E-2	6.12E-4	> C
P	WABA (8-Rod)	N/A	0.01	1.79E-1	1.71E-3	> C
P	WABA (20-Rod)	N/A	0.019	1.79E-1	3.35E-3	> C
P	Short WABA (4-Rod)	N/A	0.0075	1.71E-1	1.09E-3	> C
P	Short WABA (12-Rod)	N/A	0.013	1.71E-1	2.05E-3	> C
P	BPA (4-Rod)	N/A	0.0093	1.82E-1	1.59E-3	> C
P	BPA (10-Rod)	N/A	0.015	1.82E-1	2.99E-3	> C
P	BPA (20-Rod)	N/A	0.024	1.82E-1	5.31E-3	> C
S	Primary, Version 1	N/A	0.024	1.84E-1	3.80E-3	> C
S	Primary, Version 2	N/A	0.024	1.84E-1	3.80E-3	> C
S	Primary, Version 3	N/A	0.015	1.82E-1	3.42E-3	> C
S	Secondary, 116 Inch	N/A	0.013	1.35E-1	8.17E-4	> C
S	Secondary, 143 Inch	N/A	0.011	1.67E-1	1.16E-3	> C
S	Secondary, 157 Inch	N/A	0.0086	1.82E-1	8.18E-4	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: Salem 1
1977 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: Salem 2
1981 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: San Onofre 1
1968 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Standard	N/A	0.058	1.56E-1	N/A	N/A
C	Short, Ver. 1	N/A	0.058	1.55E-1	5.30E-3	> C
C	Short, Ver. 2	N/A	0.049	1.32E-1	5.27E-3	> C
G	Water Displacement	N/A	0.0093	1.54E-1	1.14E-3	> C
G	Standard	N/A	0.0043	1.19E-2	5.38E-4	> C
P	(4-Rod)	N/A	0.0077	1.54E-1	1.46E-3	> C
P	(12-Rod)	N/A	0.015	1.54E-1	3.31E-3	> C
P	BPA (16-Rod)	N/A	0.018	1.54E-1	4.22E-3	> C
P	WABA (4-Rod)	N/A	0.0071	1.52E-1	1.07E-3	> C
P	WABA (12-Rod)	N/A	0.013	1.52E-1	2.17E-3	> C
P	WABA (16-Rod)	N/A	0.016	1.52E-1	2.73E-3	> C
S	Primary, Version 1	N/A	0.022	1.24E-1	3.77E-3	> C
S	Secondary, 116 Inch	N/A	0.01	1.15E-1	9.53E-4	> C
S	Secondary, 137 Inch	N/A	0.011	1.36E-1	1.00E-3	> C
S	Secondary, 143 Inch	N/A	0.01	1.41E-1	1.04E-3	> C
S	Secondary, 157 Inch	N/A	0.013	1.55E-1	1.04E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: San Onofre 2
1983 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	San Onofre Part Len	13	0.54	2.53E+0	N/A	N/A
C	San Onofre Full Len	140	4.6	2.72E+1	8.75E-1	> C
I	San Onofre	316	0.92	1.84E-2	1.29E-1	> C
S	Standard	3	0.011	2.52E-3	1.92E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	5.5	2.73E+1	1.01E+0
Total	6	2.98E+1	1.01E+0

Future Waste Inventory: San Onofre 3
1984 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	San Onofre Part Len	13	0.54	2.53E+0	N/A	N/A
C	San Onofre Full Len	135	4.4	2.63E+1	8.43E-1	> C
I	San Onofre	304	0.88	1.77E-2	1.24E-1	> C
S	Standard	3	0.011	2.52E-3	1.92E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	5.3	2.63E+1	9.69E-1
Total	5.8	2.88E+1	9.69E-1

Future Waste Inventory: Seabrook 1
1995 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: Sequoyah 1
1981 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: Sequoyah 2
1982 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: Shoreham
1995 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/4; 80 Mil Thick	1866	58	1.51E+2	N/A	N/A
B	BWR/4,5,100 Mil Thic	1866	73	1.51E+2	1.11E+1	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	73	1.51E+2	1.11E+1
Total	1.3E+2	3.02E+2	1.11E+1

Future Waste Inventory: South Texas 1
1988 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: South Texas 2
1989 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: St. Lucie 1
1976 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Part Length, Ver. 2	17	0.64	2.96E+0	N/A	N/A
C	Full Length	138	4.8	2.40E+1	9.90E-1	> C
I	Millstone 2	320	1.8	2.30E-1	2.42E-1	> C
S	137 Inch Core	4	0.02	4.18E-3	2.84E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	6.7	2.42E+1	1.23E+0
Total	7.3	2.72E+1	1.23E+0

Future Waste Inventory: St. Lucie 2
1983 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	St. Lucie 2 Part Len	13	0.49	2.28E+0	N/A	N/A
C	St. Lucie 2 Full Len	140	4.2	2.45E+1	7.96E-1	> C
I	St. Lucie 2	316	1	2.09E-1	1.29E-1	> C
S	Standard	3	0.011	2.52E-3	1.92E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	5.2	2.47E+1	9.27E-1
Total	5.7	2.70E+1	9.27E-1

Future Waste Inventory: Summer
1984 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: Surry 1
1972 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Standard	N/A	0.075	1.83E-1	N/A	N/A
G	Standard	N/A	0.0049	1.19E-2	6.12E-4	> C
P	WABA (8-Rod)	N/A	0.01	1.79E-1	1.71E-3	> C
P	WABA (20-Rod)	N/A	0.019	1.79E-1	3.35E-3	> C
P	Short WABA (4-Rod)	N/A	0.0075	1.71E-1	1.09E-3	> C
P	Short WABA (12-Rod)	N/A	0.013	1.71E-1	2.05E-3	> C
P	BPA (4-Rod)	N/A	0.0093	1.82E-1	1.59E-3	> C
P	BPA (10-Rod)	N/A	0.015	1.82E-1	2.99E-3	> C
P	BPA (20-Rod)	N/A	0.024	1.82E-1	5.31E-3	> C
S	Primary, Version 1	N/A	0.024	1.84E-1	3.80E-3	> C
S	Primary, Version 2	N/A	0.024	1.84E-1	3.80E-3	> C
S	Primary, Version 3	N/A	0.015	1.82E-1	3.42E-3	> C
S	Secondary, 116 Inch	N/A	0.013	1.35E-1	8.17E-4	> C
S	Secondary, 143 Inch	N/A	0.011	1.67E-1	1.16E-3	> C
S	Secondary, 157 Inch	N/A	0.0086	1.82E-1	8.18E-4	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: Surry 2
1973 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Standard	N/A	0.075	1.83E-1	N/A	N/A
G	Standard	N/A	0.0049	1.19E-2	6.12E-4	> C
P	WABA (8-Rod)	N/A	0.01	1.79E-1	1.71E-3	> C
P	WABA (20-Rod)	N/A	0.019	1.79E-1	3.35E-3	> C
P	Short WABA (4-Rod)	N/A	0.0075	1.71E-1	1.09E-3	> C
P	Short WABA (12-Rod)	N/A	0.013	1.71E-1	2.05E-3	> C
P	BPA (4-Rod)	N/A	0.0093	1.82E-1	1.59E-3	> C
P	BPA (10-Rod)	N/A	0.015	1.82E-1	2.99E-3	> C
P	BPA (20-Rod)	N/A	0.024	1.82E-1	5.31E-3	> C
S	Primary, Version 1	N/A	0.024	1.84E-1	3.80E-3	> C
S	Primary, Version 2	N/A	0.024	1.84E-1	3.80E-3	> C
S	Primary, Version 3	N/A	0.015	1.82E-1	3.42E-3	> C
S	Secondary, 116 Inch	N/A	0.013	1.35E-1	8.17E-4	> C
S	Secondary, 143 Inch	N/A	0.011	1.67E-1	1.16E-3	> C
S	Secondary, 157 Inch	N/A	0.0086	1.82E-1	8.18E-4	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: Susquehanna 1
1983 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/4; 80 Mil Thick	4584	1.4E+2	3.71E+2	N/A	N/A
B	BWR/4,5,100 Mil Thic	4584	1.8E+2	3.71E+2	2.73E+1	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	1.8E+2	3.71E+2	2.73E+1
Total	3.2E+2	7.42E+2	2.73E+1

Future Waste Inventory: Susquehanna 2
1985 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/4; 80 Mil Thick	4244	1.3E+2	3.43E+2	N/A	N/A
B	BWR/4,5,100 Mil Thic	4244	1.7E+2	3.43E+2	2.52E+1	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	1.7E+2	3.43E+2	2.52E+1
Total	3E+2	6.87E+2	2.52E+1

Future Waste Inventory: Three Mile Island 1
1974 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Standard	146	8.6	2.79E+1	N/A	N/A
G	Standard	N/A	0.0072	1.91E-2	8.69E-4	> C
P	Gray Ax. Power Shap.	N/A	0.032	1.91E-1	3.96E-3	> C
P	Burnable Poison	N/A	0.026	1.84E-1	4.72E-3	> C
P	Axial Power Shap.	N/A	0.026	1.91E-1	2.90E-3	> C
S	Primary Source	N/A	0.00045	1.74E-1	5.49E-5	> C
S	Regenerative	4	0.084	6.88E-1	4.11E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0.084	6.88E-1	4.11E-3
Total	8.7	2.86E+1	4.11E-3

Future Waste Inventory: Trojan
1976 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: Turkey Point 3
1972 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Standard	N/A	0.075	1.83E-1	N/A	N/A
G	Standard	N/A	0.0049	1.19E-2	6.12E-4	> C
P	WABA (8-Rod)	N/A	0.01	1.79E-1	1.71E-3	> C
P	WABA (20-Rod)	N/A	0.019	1.79E-1	3.35E-3	> C
P	Short WABA (4-Rod)	N/A	0.0075	1.71E-1	1.09E-3	> C
P	Short WABA (12-Rod)	N/A	0.013	1.71E-1	2.05E-3	> C
P	BPA (4-Rod)	N/A	0.0093	1.82E-1	1.59E-3	> C
P	BPA (10-Rod)	N/A	0.015	1.82E-1	2.99E-3	> C
P	BPA (20-Rod)	N/A	0.024	1.82E-1	5.31E-3	> C
S	Primary, Version 1	N/A	0.024	1.84E-1	3.80E-3	> C
S	Primary, Version 2	N/A	0.024	1.84E-1	3.80E-3	> C
S	Primary, Version 3	N/A	0.015	1.82E-1	3.42E-3	> C
S	Secondary, 116 Inch	N/A	0.013	1.35E-1	8.17E-4	> C
S	Secondary, 143 Inch	N/A	0.011	1.67E-1	1.16E-3	> C
S	Secondary, 157 Inch	N/A	0.0086	1.82E-1	8.18E-4	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: Turkey Point 4
1973 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Standard	N/A	0.075	1.83E-1	N/A	N/A
G	Standard	N/A	0.0049	1.19E-2	6.12E-4	> C
P	WABA (8-Rod)	N/A	0.01	1.79E-1	1.71E-3	> C
P	WABA (20-Rod)	N/A	0.019	1.79E-1	3.35E-3	> C
P	Short WABA (4-Rod)	N/A	0.0075	1.71E-1	1.09E-3	> C
P	Short WABA (12-Rod)	N/A	0.013	1.71E-1	2.05E-3	> C
P	BPA (4-Rod)	N/A	0.0093	1.82E-1	1.59E-3	> C
P	BPA (10-Rod)	N/A	0.015	1.82E-1	2.99E-3	> C
P	BPA (20-Rod)	N/A	0.024	1.82E-1	5.31E-3	> C
S	Primary, Version 1	N/A	0.024	1.84E-1	3.80E-3	> C
S	Primary, Version 2	N/A	0.024	1.84E-1	3.80E-3	> C
S	Primary, Version 3	N/A	0.015	1.82E-1	3.42E-3	> C
S	Secondary, 116 Inch	N/A	0.013	1.35E-1	8.17E-4	> C
S	Secondary, 143 Inch	N/A	0.011	1.67E-1	1.16E-3	> C
S	Secondary, 157 Inch	N/A	0.0086	1.82E-1	8.18E-4	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: Vermont Yankee
1972 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/4; 80 Mil Thick	3107	97	2.51E+2	N/A	N/A
B	BWR/4,5,100 Mil Thic	3107	1.2E+2	2.51E+2	1.85E+1	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	1.2E+2	2.51E+2	1.85E+1
Total	2.2E+2	5.03E+2	1.85E+1

Future Waste Inventory: Vogtle 1
1987 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: Vogtle 2
1989 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: Washington Nuclear 1
1995 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: Washington Nuclear 2
1984 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
B	BWR/4,5,100 Mil Thic	4414	1.7E+2	3.57E+2	N/A	N/A

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	1.7E+2	3.57E+2	0.00E+0

Future Waste Inventory: Washington Nuclear 3
1995 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: Waterford 3
1985 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	San Onofre Part Len	12	0.5	2.34E+0	N/A	N/A
C	San Onofre Full Len	130	4.2	2.53E+1	8.12E-1	> C
I	Waterford	293	0.97	2.11E-1	1.35E-1	> C
S	Standard	3	0.011	2.52E-3	1.92E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	5.2	2.55E+1	9.49E-1
Total	5.7	2.78E+1	9.49E-1

Future Waste Inventory: Watts Bar 1
1992 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: Watts Bar 2
1995 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: Wolf Creek
1985 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Full Length, Ver. 1	N/A	0.068	1.88E-1	N/A	N/A
C	Full Length, Ver. 2	N/A	0.082	1.88E-1	6.82E-3	> C
C	Full Length, Ver. 3	N/A	0.068	1.88E-1	7.15E-3	> C
C	Hybrid	N/A	0.042	1.88E-1	5.83E-3	> C
C	Part Length	N/A	0.045	1.88E-1	7.32E-3	> C
G	Standard	N/A	0.0059	1.38E-2	7.37E-4	> C
P	WABA (4-Rod)	N/A	0.0077	1.79E-1	1.13E-3	> C
P	WABA (16-Rod)	N/A	0.017	1.79E-1	2.85E-3	> C
P	WABA (24-Rod)	N/A	0.023	1.79E-1	3.98E-3	> C
P	BPA (4-Rod)	N/A	0.0087	1.82E-1	1.51E-3	> C
P	BPA (10-Rod)	N/A	0.013	1.82E-1	2.64E-3	> C
P	BPA (16-Rod)	N/A	0.017	1.82E-1	3.79E-3	> C
P	BPA (24-Rod)	N/A	0.022	1.83E-1	5.30E-3	> C
S	Primary, Version 1	N/A	0.018	1.82E-1	4.50E-4	> C
S	Primary, Version 2	N/A	0.016	1.82E-1	2.80E-3	> C
S	Primary, Version 3	N/A	0.023	1.82E-1	5.15E-3	> C
S	Secondary; on Spider	N/A	0.011	1.83E-1	1.15E-3	> C
S	Secondary,12 BP Rods	N/A	0.018	1.82E-1	3.16E-3	> C
S	Secondary,20 BP Rods	N/A	0.023	1.82E-1	4.73E-3	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: Yankee-Rowe
1961 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: Zion 1
1973 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Standard	N/A	0.075	1.83E-1	N/A	N/A
G	Standard	N/A	0.0049	1.19E-2	6.12E-4	> C
P	WABA (8-Rod)	N/A	0.01	1.79E-1	1.71E-3	> C
P	WABA (20-Rod)	N/A	0.019	1.79E-1	3.35E-3	> C
P	Short WABA (4-Rod)	N/A	0.0075	1.71E-1	1.09E-3	> C
P	Short WABA (12-Rod)	N/A	0.013	1.71E-1	2.05E-3	> C
P	BPA (4-Rod)	N/A	0.0093	1.82E-1	1.59E-3	> C
P	BPA (10-Rod)	N/A	0.015	1.82E-1	2.99E-3	> C
P	BPA (20-Rod)	N/A	0.024	1.82E-1	5.31E-3	> C
S	Primary, Version 1	N/A	0.024	1.84E-1	3.80E-3	> C
S	Primary, Version 2	N/A	0.024	1.84E-1	3.80E-3	> C
S	Primary, Version 3	N/A	0.015	1.82E-1	3.42E-3	> C
S	Secondary, 116 Inch	N/A	0.013	1.35E-1	8.17E-4	> C
S	Secondary, 143 Inch	N/A	0.011	1.67E-1	1.16E-3	> C
S	Secondary, 157 Inch	N/A	0.0086	1.82E-1	8.18E-4	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

Future Waste Inventory: Zion 2
1974 - 2010

Type	Name	Number	Weight	Cu. Vol.	Red. Vol.	Class
C	Standard	N/A	0.075	1.83E-1	N/A	N/A
G	Standard	N/A	0.0049	1.19E-2	6.12E-4	> C
P	WABA (8-Rod)	N/A	0.01	1.79E-1	1.71E-3	> C
P	WABA (20-Rod)	N/A	0.019	1.79E-1	3.35E-3	> C
P	Short WABA (4-Rod)	N/A	0.0075	1.71E-1	1.09E-3	> C
P	Short WABA (12-Rod)	N/A	0.013	1.71E-1	2.05E-3	> C
P	BPA (4-Rod)	N/A	0.0093	1.82E-1	1.59E-3	> C
P	BPA (10-Rod)	N/A	0.015	1.82E-1	2.99E-3	> C
P	BPA (20-Rod)	N/A	0.024	1.82E-1	5.31E-3	> C
S	Primary, Version 1	N/A	0.024	1.84E-1	3.80E-3	> C
S	Primary, Version 2	N/A	0.024	1.84E-1	3.80E-3	> C
S	Primary, Version 3	N/A	0.015	1.82E-1	3.42E-3	> C
S	Secondary, 116 Inch	N/A	0.013	1.35E-1	8.17E-4	> C
S	Secondary, 143 Inch	N/A	0.011	1.67E-1	1.16E-3	> C
S	Secondary, 157 Inch	N/A	0.0086	1.82E-1	8.18E-4	> C

	Weight	Cu. Vol.	Red. Vol.
Total LECC	0	0.00E+0	0.00E+0
Total GTCC	0	0.00E+0	0.00E+0
Total	0	0.00E+0	0.00E+0

HARDWARE TOTALS	Num. of Types	Number	Weight	Cu. Vol.	Red. Vol.	% GTCC
BWR Fuel Channels	1	21463	340	7.04E+3	5.17E+2	100.0
Control Elements	7	1853	77	3.56E+2	1.44E+1	100.0
Guide Tube Plugs	0	0	0	0.00E+0	0.00E+0	0.0
Instrumentation	9	4253	28	5.08E+0	3.72E+0	100.0
Burnable Poisons	0	0	0	0.00E+0	0.00E+0	0.0
Incore Sources	6	89	0.9	5.55E+0	6.75E-2	100.0
TOTALS	23	27658	350	7.40E+3	5.35E+2	100.0

Total Estimated: 95
Number Incomplete: 72
Percentage Not Represented: 75.8

BIOGRAPHICAL SKETCH

The author was born on April 18, 1964 in Erie, Pennsylvania. He is the son of Charles and Jane Williamson and the brother of Robert. His family moved to Florida when the author was five, and currently live in Sarasota. The author completed high school at Pine View School for the Gifted in June 1982, and then enrolled at the University of Florida. The author received his Bachelor of Science in Nuclear Engineering with High Honors in May 1986, and his Master of Engineering in December of 1988, both from the University of Florida. The author then continued his education at the University of Florida in pursuit of his Doctor of Philosophy.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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James S. Tulenko, Chairman
Professor of Nuclear
Engineering Sciences

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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William G. Vernetson
Associate Engineer of Nuclear
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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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This dissertation was submitted to the Graduate Faculty of the College of Engineering and to the Graduate School and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

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